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PRELIMINARY REPORT

ON THE

LEAD AND ZINC DEPOSITS

OF

SOUTHWESTERN WISCONSIN.

BY

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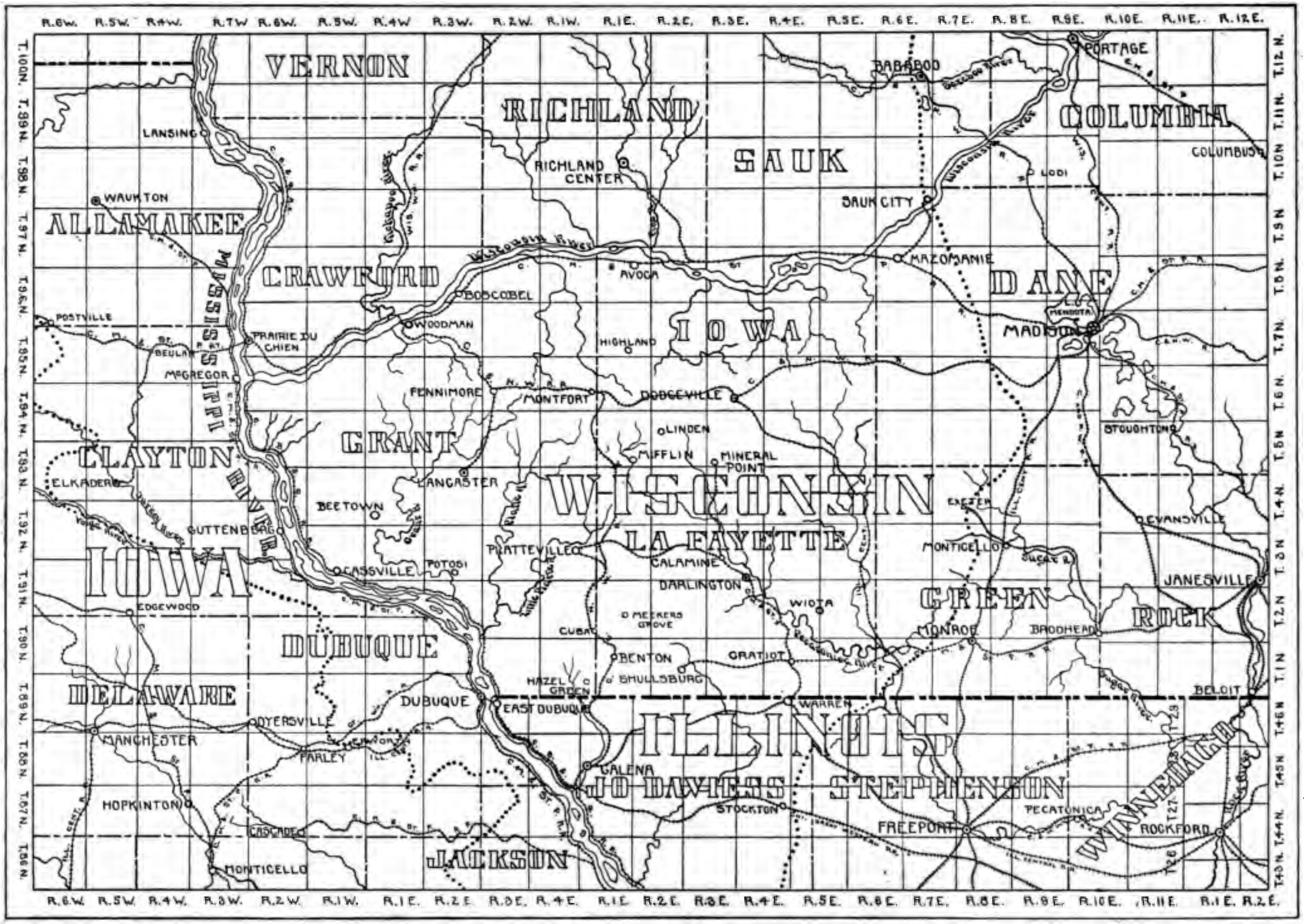

General map of Southwestern Wisconsin and parts of adjoined States.

THE LEAD AND ZINC DEPOSITS OF SOUTH-WESTERN WISCONSIN.

CHAPTER I.

INTRODUCTION.

HISTORICAL.

The lead and zinc mines of the Mississippi valley may be grouped into three divisions:[1] (1) Those of the Ozark region; (2) those of the Upper Mississippi valley; and (3) those of outlying districts including (a) southern Arkansas and (b) an area in Kentucky and southern Illinois. The Upper Mississippi valley district comprises: (1) Grant, Lafayette and Iowa counties, Wisconsin; (2) Jo Daviess county, Illinois; and (3) Dubuque county, Iowa. From certain other counties adjoining these five, small amounts of ore have been produced, and the main production has come from the three Wisconsin counties mentioned. The lead and zinc deposits of these Wisconsin counties form the subject of this report.[2]

In the Upper Mississippi valley, lead seems to have been discovered by Nicholas Perrott about 1692.[3] This metal was also noted by Le Sueur in 1700 or 1701, and by John Carver in 1766. The first mining in the district was done on the

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[1] C. R. Van Hise and H. F. Bain: "Lead- and zinc-deposits of the Mississippi valley, U. S. A.," Trans. Inst. Mining Engineers (England), vol. xxiii, p. 378, 1902.

[2] See plate I.

[3] Arthur Winslow: "Lead and zinc deposits," Mo. Geol. Survey, vol. vi, p. 145, 1894.

site of the present city of Dubuque in 1788 by Julien Dubuque, who obtained from the Indians land on which lead had been discovered a few years previously. After Dubuque's death in 1810, little was done until after 1820, and before 1830 mining had become quite general in the vicinity of Dubuque and Galena, and also in southwestern Wisconsin. From this time down to the present day mining has been carried on continuously in the Upper Mississippi valley district, with certain periods in which the district figured prominently as a producer of lead and zinc.

The early work, and in fact that for years afterward, was devoted entirely to the mining of lead, the zinc ores being unrecognized or, when recognized, regarded as of little value. It was not until some forty years ago that zinc ores were mined in this region, and the amount of these ores produced rapidly increased until the district became more important as a source of zinc than of lead. Of late years, due to a number of causes, the activity of the district has decreased, but the last two years,—especially 1902,—have seen a marked revival in mining interest,—a revival which promises well to continue.

The ores mined are galena or "mineral" (sulphide of lead), smithsonite or "dry-bone" (carbonate of zinc), and sphalerite or "black jack" (sulphide of zinc). In relative amount of production sphalerite is the most important, smithsonite of less importance, and galena less still. The future will undoubtedly witness a continued increase in the importance of sphalerite.

PREVIOUS REPORTS AND MAPS.

In addition to some earlier reports by Daniels, Percival and Whitney,[1] the former Geological Survey of Wisconsin issued two important papers dealing with the lead and zinc deposits. The earlier of these was by Moses Strong,[2] and the latter by

[1] A list of these reports will be found on a later page.

[2] "Geology and topography of the lead region," Geol. of Wis., vol. ii, pp. 643–752, 1877.

the Chief Geologist, T. C. Chamberlin.[1] The Survey also issued an atlas of maps, included in which are a number relating directly to the lead and zinc region. These are (1) geological maps of the counties, (2) geological and topographical maps, scale about one inch to one mile, of the important ore-producing districts, and (3) large scale crevice maps of the different districts. The latter show in detail a large number of the crevices from which lead, or lead and zinc, ores have been obtained.[2]

Recently C. R. Van Hise[3] has discussed the principles of ore deposition and has noted particular applications of these principles to the Upper Mississippi Valley lead and zinc district, and H. F. Bain[4] has presented a report on the lead and zinc deposits of the Ozark region.

The report by Chamberlin, just cited, is a very complete and exhaustive account of the district under consideration,—by far the best account written. The paper by Van Hise presents in a masterly way the modern theory and principles of ore deposition and the application of the same to the Wisconsin district, while the paper by Bain discusses, in the light of these principles, the closely related lead and zinc deposits of Missouri. To these three papers the writer is especially indebted,—in fact the indebtedness is so great that it is practically impossible to refer to the proper source each of the statements made in this report of facts which have already been stated by others. For

[1] "The ore deposits of southwestern Wisconsin," Ibid., vol. iv, pp. 365–571, 1882.

[2] The reports and atlas of the former Geological Survey are unfortunately out of print, but they can be obtained at times from dealers in second-hand books. The atlas plates of importance in the lead and zinc district are: V to IX (sometimes numbered III to VII), XIII, XVI, XXXI to XL.

[3] "Some principles controlling the deposition of ores," Trans. Amer. Inst. Mining Eng., vol. xxx, pp. 27–177, 1901.

[4] "Preliminary report on the lead and zinc deposits of the Ozark region, with an introduction by C. R. Van Hise, and chapters on the physiography and geology by G. I. Adams," 22nd Ann. Rept. U. S. Geol. Survey, pt. ii, pp. 23–227, 1902.

this reason this general acknowledgment is here made, not only to these papers just mentioned, but also to others treating of this region. It seldom happens that a preliminary report like the present has to deal with a district which has been so carefully studied by others; and were it not for this previous work on the district it would have been impossible in the brief period available for the preparation of this report to have presented anything but an account of certain limited parts of the district.

Three of the sheets of the Topographic Atlas of the United States, published by the United States Geological Survey, include a large part of the territory in the Wisconsin lead and zinc district. These are the Elkader, Lancaster and Mineral Point sheets; the scale of these is one-half inch to the mile and the contour interval is twenty feet.[1]

Bibliography.

Below will be found a partial list of the papers dealing with the Upper Mississippi Valley lead and zinc district. This list does not contain papers which treat solely of the paleontology and the Pleistocene geology.

1842

J. T. HODGE: "On the Wisconsin and Missouri lead region," Amer. Jour. Sci., ser. i, vol. xliii, pp. 35–72.

1854

EDWARD DANIELS: "Some features of the lead district of Wisconsin," Proc. Boston Soc. Nat. Hist., vol. v, pp. 387–389.

EDWARD DANIELS: First Ann. Rept. Geol. Survey of Wis., pp. 7–66.

J. D. WHITNEY: "Metallic wealth of the United States," pp. 403–417.

1855

J. G. PERCIVAL: Ann. Rept. Geol. Survey of Wis., pp. 7–101.

1858

J. D. WHITNEY: Geol. of Iowa, vol. i, pt. i, pp. 422–471.

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[1] These sheets may be obtained from the Director of the U. S. Geological Survey, Washington, D. C. The price is five cents each.

1862

J. D. WHITNEY: "Report on the lead region of Wisconsin," Geol. Survey of Wis., vol. i, pp. 73–420.

1866

J. D. WHITNEY: "Geology of the lead region," Geol. Survey of Ill., vol. i, pp. 153–207. Also in Economical Geol. of Ill., vol. i, pp. 188–162, 1882.

1870

C. A. WHITE: "Lead and zinc," Geol. Survey of Iowa, vol. ii, pp. 339–342.

1873

JAMES SHAW: "Geology of northwestern Illinois," Geol. Survey of Ill., vol. v, pp. 1–24. Also in Economical Geol. of Ill., vol. iii, pp. 1–20, 1882.

JAMES SHAW: "Geology of Jo Daviess county," Geol. Survey of Ill., vol. v, pp. 25–56. Also in Economical Geol. of Ill., vol. iii, pp. 20–54, 1882.

1877

MOSES STRONG: "Geology and topography of the lead region," Geol. of Wis., vol. ii, pp. 643–752.

1882

T. C. CHAMBERLIN: "The ore deposits of southwestern Wisconsin," Geol. of Wis., vol. iv, pp. 365–571.

1883

MOSES STRONG: "Lead and zinc ores," Geol. of Wis., vol. i, pp. 637–655.

1893

W. P. BLAKE: "The progress of geological surveys in the state of Wisconsin—a review and bibliography," Trans. Wis. Acad. Sci., Arts and Letters, vol. ix, pp. 225–231.

ARTHUR WINSLOW: "Notes on the lead and zinc deposits of the Mississippi valley and the origin of the ores," Jour. of Geol., vol. i, pp. 612–619.

1894

W. P. BLAKE: "Wisconsin lead and zinc deposits," Bull. Geol. Soc. of Amer., vol. v, pp. 25–32.

W. P. Blake: "The mineral deposits of southwestern Wisconsin," Trans. Amer. Inst. Mining Eng., vol. xxii, pp. 558–568. Also in Amer. Geol., vol. xii, pp. 237–248.

W. P. Blake: "Discussion on lead and zinc deposits of the Mississippi valley," Trans. Amer. Inst. Mining Eng., vol. xxii, pp. 621–634.

W. P. Blake: "Discussion on genesis of ore deposits," Trans. Amer. Inst. Mining Eng., vol. xxiii, p. 587.

T. C. Chamberlin: "Discussion on Wisconsin lead and zinc deposits," Bull. Geol. Soc. Amer., vol. v, p. 32.

W. P. Jenney: "Lead and zinc deposits of the Mississippi valley," Trans. Amer. Inst. Mining Eng., vol. xxii, pp. 171–225, 642–646; especially pp. 208–212.

A. G. Leonard: "Occurrence of zinc in northeastern Iowa," Proc. Iowa Acad. Sci., vol. i, pt. iv, pp. 48–52.

Arthur Winslow: "Lead and zinc deposits," Mo. Geol. Survey, vol. vi and vii; especially vol. vi, pp. 135–149.

Arthur Winslow: "Discussion on lead and zinc deposits of the Mississippi valley," Trans. Amer. Inst. Mining Eng., vol. xxii, pp. 634–636.

1895

W. H. Hobbs: "A contribution to the mineralogy of Wisconsin," Bull. Univ. of Wis., sci. ser., vol. i, pp. 109–156. Also in Zeitsch. f. Kryst., vol. xxv, pp. 257–275.

A. G. Leonard: "Origin of the Iowa lead and zinc deposits," Amer. Geol., vol. xvi, pp. 288–294.

A. G. Leonard: "Lansing lead mines," Proc. Iowa Acad. Sci., vol. ii, pp. 36–38.

1896

A. G. Leonard: "Lead and zinc deposits of Iowa," Eng. and Mining Jour., vol. lxi, p. 614.

A. G. Leonard: "Lead and zinc. A description of the mines of Iowa in the Upper Mississippi region," Colliery Eng., vol. xvii, pp. 121–122.

1897

A. G. Leonard: "Lead and zinc deposits of Iowa," Iowa Geol. Survey, vol. vi, pp. 9–66.

1900

Samuel Calvin and H. F. Bain: "Geology of Dubuque county," Iowa [illegible] vol. x, pp. 379–622; especially pp. 480–597.

G. D. HUBBARD: "The Blue Mound quartzite," Amer. Geol., vol. xxvi, pp. 163-168.

1901

S. H. BALL and A. F. SMITH: "The geology and ore deposition of the Benton district, Lafayette county, Wisconsin," Thesis, Univ. of Wis. Not published, but in University library.

C. R. VAN HISE: "Some principles controlling the deposition of ores," Trans. Amer. Inst. Mining Eng., vol. xxx, pp. 27-177; especially pp. 102-109.

1902

H. F. BAIN: "Preliminary report on the lead and zinc deposits of the Ozark region, with an introduction by C. R. Van Hise, and chapters on the physiography and geology by G. I. Adams," 22nd Ann. Rept. U. S. Geol. Survey, pt. ii, pp. 23-227.

C. R. VAN HISE and H. F. BAIN: "Lead- and zinc-deposits of the Mississippi valley, U. S. A.," Trans. Inst. Mining Engineers (England), vol. xxiii, pp. 376-434; especially pp. 409-420.

OBJECT AND SCOPE OF THIS REPORT.

In the preparation of this report three objects have been kept in mind: (1) To attempt to bring the knowledge of the geology, more especially the geology of the ore deposits, of the district down to the present time,—no complete discussion of the district has been published since the report by Chamberlin[1] twenty years ago,—and to present such additional information as may have been obtained in the progress of the work. (2) To present an account of the district in a somewhat brief report which would be of use to those interested in the district and to the public in general. (3) To give a careful and as accurate a statement as possible concerning the present and future outlook for mining in the district. How far the writer has succeeded in accomplishing these ends is for others than himself to judge. He recognizes, probably more keenly than anyone else, the difficulties in making a brief report on a district which has been so

[1] "The ore deposits of southwestern Wisconsin," Geol. of Wis., vol. iv, pp. 365-571, 1882.

much worked over by others and concerning which such different views have been held.

This account makes no pretense to completeness. The time available for the field work and for the preparation of the report was too brief to allow of anything more than a preliminary report.

ACKNOWLEDGMENTS.

The writer's indebtedness to previous reports on this district has already been noted.[1]

To the Director of the Survey, Professor E. A. Birge, and to the consulting Geologist, Professor C. R. Van Hise, thanks are due for many kindnesses. The work was carried on under the general supervision of the latter, and the assistance and helpful suggestions derived from him were a very important aid. Thanks are due to Dr. H. Foster Bain for kindly criticisms. In part of the field work Mr. E. E. Ellis of Northwestern University, acted as assistant.

The people of the district have been uniformly kind and generous in their interest in the work and in furnishing freely such information as it was possible to give. A list of those to whom thanks are due would include nearly all the mine owners, managers and superintendents in the district, as well as a number of individuals who are not directly interested in mining.

[1] P. 3.

CHAPTER II.

PHYSICAL FEATURES.

TOPOGRAPHY.

The surface of this district (including Grant, Lafayette and Iowa counties) is fairly uniform in its general features throughout these three counties, with the exception of the immediate valley of the Wisconsin on the north and that of the Mississippi on the west. Away from the vicinity of these two large valleys the topographic features may be grouped under three heads: (1) the mounds, (2) the uplands, and (3) the valleys.

The mounds.

The important mounds are the Blue, Platte and Sinsinawa. These are roughly circular elevations of small extent, usually with flat tops, which rise some 200 feet above the surrounding country. These mounds closely resemble others of the same character which are found to the east of the lead and zinc district in Wisconsin, and also to the south in Illinois. In general the mounds are capped by Niagara limestone, which has acted as a protection to the underlying softer Hudson River shales. This limestone frequently contains large amounts of flints, and at the west of the Blue mounds the upper rock layer is of a flinty or quartzite-like nature.[1] These caps of Niagara limestone are

[1] Moses Strong: "Geology and topography of the lead region," Geol. of Wis., vol. ii, p. 661, 1877.

G. D. Hubbard: "The Blue Mound quartzite," Amer. Geol., vol. xxvi, pp. 163–168, 1900.

all that is now left of a layer of this formation which has been removed by erosion from over a large part, if not from the whole, of the district.

The uplands.

The uplands consist of rather level-topped elevations or ridges which separate the valleys. In fact the whole upland surface may be considered as a gently undulating plain which slopes gradually to the southwest. Above the plain rise the scattered mounds and in it have been cut the numerous valleys. The general features of this plain may be seen from almost any of the larger stream divides of the region. A very good view of the topographic features of the district can be had from the Chicago and Northwestern railroad which traverses the plain from Blue Mounds to Fennimore along what is known as the Military ridge; also along the Lancaster branch of this railroad and along the Galena branch north of Cuba City.

The valleys.

Each valley, as one descends it, is seen to consist first of a sag with gently sloping convex sides which merge gradually into the general surface of the upland plain. Lower down the valley floor has a steeper slope and the sides are steeper also, but still of gradual slope. Farther down still the narrow valley widens out, has a less marked slope and acquires a rather wide flat bottom. These flat-bottomed valleys are characteristic of all the larger streams and of many of the smaller ones also. At times the calley is bounded by steep slopes or cliffs, and these cliffs are commonly of Trenton limestone. Sometimes they are of Galena limestone, and much less commonly of St. Peter sandstone. A good example of these sandstone cliffs may be seen just west of Mineral Point, where the St. Peter is more consolidated than usual. The bottoms of the valleys are from 100 to 400 feet, in places more, below the general level of the district, and continuous slopes of 200 feet in altitude are common along the valley sides.

The peneplain.

The present topography of the district is due to sub-aerial erosion acting on approximately horizontal strata. The general history of the erosion may be summed up as follows: After the deposition of the Niagara limestone there is no absolute proof that other and later formations were deposited. If such were deposited they have been entirely removed by erosion, and of such earlier erosion we have no certain records. There is, however, one period of erosion which has left marked records, and this is the period in which the land stood in a uniform position long enough for streams to reduce the whole district to a nearly level region or peneplain. This peneplain is now represented by the level uplands already described. The only parts of the district which were not reduced to the general level are the mounds, which rise as monadnocks above the peneplain. The date of the formation of this peneplain is not certainly known, but it may be of Tertiary age, and if so is thus later than the possibly Cretaceous peneplain which is exhibited farther north in central Wisconsin.[1] After the formation of this peneplain the land was elevated, and erosion again began its work cutting into the surface and forming the present valleys. This elevation took place before Glacial time, and there is some evidence to show that at one time during this period of erosion the land stood at a somewhat higher altitude than at present. Since the revival of erosion a large portion of the district has been lowered, and the region is now in a stage where the streams are not so rapidly deepening their valleys as the valleys are widening. The district has passed through the stage of most marked relief and has entered on the stage where future erosion will tend to subdue rather than to accentuate the present differences of topography. The district may thus be said to be intermediate between maturity and old age, although much nearer the former than the latter.

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[1] C. R. Van Hise: "A central Wisconsin baselevel," Science, new ser., vol. iv, pp. 57–59, 1896. "A northern Michigan baselevel," Ibid., pp. 217–220.

Amount of erosion.

As an approximate estimate of material which has been removed from the district since the formation of the peneplain and the subsequent reelevation of the land it may be said that the bulk of the hills, or the uplands between the streams, equals approximately the cubic contents of the valleys.[1] In other words, if the district were to be leveled off the resulting surface would be about half way between the bottoms of the main valleys and the uplands (not the hills formed by the mounds). If the main valleys average 300 to 400 feet below the peneplain surface, we have a sheet of material, 150 to 200 feet in thickness and extending over the whole district, which has been removed by erosion since the elevation of the land subsequent to the formation of the peneplain. This period of elevation dates late in geological time, although antedating the Glacial period. That erosion may have removed a greater thickness than this is probable from a consideration of the soils.[2]

THE DRIFTLESS AREA.[3]

Covering the northern states is a layer of unconsolidated material known as the glacial drift, or simply as the drift. This varies in thickness from nothing up to a few hundred feet and is composed of sometimes stratified and sometimes unstratified mixtures of clay, rock-flour, sand, gravel and boulders of various sizes. Beneath the drift the solid rock is commonly scratched, smoothed or polished, and there is a sharp line of demarcation between this rock and the overlying material. The surface of the drift is now rough and hilly, now undulating, and now smooth. There is a lack of system in the arrangement of the topographic features and the streams, which wander about often apparently aimlessly. Moreover, none but the larger streams

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[1] See page 18.

[2] T. C. Chamberlin and R. D. Salisbury: "Preliminary paper on the driftless area of the Upper Mississippi valley," 6th Ann. Rept. U. S. Geol. Survey, p. 257, 1885.

[3] For a detailed account of the driftless area consult the paper by T. C. Chamberlin and R. D. Salisbury just cited. The area is enclosed
line on plate I.

have well defined valleys, and there are numerous swamps and lakes. The district is topographically young,—very young, at least away from the southern edge of the drift. These features are due to a great continental glacier which came from the north and extended as far south as the Ohio and Missouri rivers.

Lying well north of the southern limit of, and completely surrounded by, this drift-covered area is a district which has no drift and which possesses features markedly different from those just mentioned. This is known as the driftless area.[1] There is no drift here; the underlying rock is not scratched or smoothed and it is not sharply marked off from the unconsolidated material above; the topographic features are systematized, and even the smaller streams have well defined valleys and comparatively straight courses; there are no swamps, except along river bottoms, and no lakes; the district is topographically mature. This driftless area, comprising some 10,000 square miles in the Upper Mississippi valley, lies mostly in southwestern Wisconsin but enters adjacent portions of Minnesota, Iowa and Illinois. Grant, Lafayette and Iowa counties, Wisconsin, lie wholly within the driftless area.

The reason, or reasons, why this district, which is not of higher altitude than the surrounding region,—even lower than much of it,—escaped glaciation while the surrounding country was covered by ice, has been a subject for speculation and investigation. It is generally conceded that the lack of glaciation is chiefly due to the fact that the ice, coming from the north and northeast, had its main currents deflected by the large valleys of lake Superior and lake Michigan and by the high lands in Wisconsin to the north and northeast of the driftless area. The possibility of local glacial deposits in this district has been noted,[2] and the fact that the district was never covered by mov-

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[1] See plate I.

[2] G. H. Squier: "Studies in the driftless area of Wisconsin," Jour. of Geol., vol. v, pp. 825–836, 1897. Ibid., vol. vi, pp. 182–192, 1898. Ibid., vol. vii, pp. 79–82, 1899.

F. W. Sardeson: "On glacial deposits in the driftless area," Amer. Geol., vol. xx, pp. 392–403, 1897.

ing ice, while the entire surrounding country was thus deeply covered, is one of the most peculiar and striking phenomena in the whole range of glacial history.

SOILS.

Unlike the soils of the northern states in general, which are composed of material which has no immediate relationship to the underlying rock, the soils of the driftless area have the most intimate connection with subjacent rock. In fact these soils are derived by a process of decay from the country rock, and for this reason the character of the soil in any particular part of the driftless area is conditioned by the character of the underlying rock. The soil in a limestone area will thus differ widely from the soil of an area underlain by sandstone. In the latter the soil is composed largely of silica, in the fomer the soil does not closely resemble the original limestone but is mainly clay derived from this limestone. In other words, the limestone soils do not have the composition of the original rock, but are made up of the non-essential constitutents, or what might be termed the impurities, of that rock.

Composition of the soils.

The main limestone of the district,—the Galena,—consists essentially of a mixture of calcium carbonate and magnesium carbonate, together with certain impurities. These impurities are chiefly three substances: (1) quartz, (2) oxide (and probably carbonate) of iron, (3) clay. When the limestone is exposed to the agents of weathering the two carbonates just mentioned are dissolved and carried away by percolating waters, while the impurities of the rock in general remain. The chemical composition and the relative percentages of the components of the rock and those of the soils thus differ materially. Chemically the soils contain a very large percentage of silica which comes, first, from the flint, which is abundant in the limestone, and, second, from the clay which is a hydrous aluminous silicate.

No series of analyses of the Galena limestone are available.

The accompanying analysis[1] of selected fresh samples of this rock shows nearly 96 per cent. of soluble material (calcium

Analysis of Galena limestone.

Carbonate of lime, $CaCO_3$	54.33
Carbonate of magnesia, $MgCO_3$	41.56
Sesquioxide of iron, Fe_2O_3	.90
Alumina, Al_2O_3	.99
Silica, SiO_2	2.10
Total	99.88

carbonate and magnesium carbonate), which is carried away in the complete weathering of the rock to soil, and only 4 per cent. of impurities, which in the main remain in the soil after the removal of the above carbonates. The samples from which this analysis was made contained no flint nodules, which are so abundant in some parts of the limestone, and no noticeable clayey laminæ. So the average of the whole bulk of the Galena limestone would contain considerably more silica and alumina than is shown by this analysis. There are no collected data by which an accurate estimate of the percentages of these substances, and other impurities, in the limestone could be made, but a rough estimate will show approximately 10 per cent. of impurities and 90 per cent. of the carbonates. In other words, from the weathering of a thickness of 100 feet of the limestone a thickness of approximately 10 feet of soil would result. Actually this thickness of soil would be greater than just stated, for the soil is less compact than the limestone and contains other material (such as water and organic matter) than that which was derived from the limestone.

The accompanying analyses of clays, known as residual clays because they are formed from the underlying rock, from this district will give a good idea of their general composition.

[1] Made by Professor W. W. Daniels of the University of Wisconsin.

Analyses of residual clays from the driftless area.

	No. 1.	No. 2.	No 3.	No. 4.	No. 5.	No. 6.
SiO_2	71.13	49.59	53.09	49.13	70.48	70.79
Al_2O_3	12.50	18.64	21.43	20.08	13.26	12.87
Fe_2O_3	5.52	17.19	8.53	11.04	4.20	4.50
FeO	.45	.27	.86	.93	.....	.....
TiO_2	.45	.28	.16	.13	.50	.50
P_2O_5	.02	.03	.03	.04	.....	.....
MnO	.04	.01	.03	.06	Trace	Trace
CaO	.85	.93	.95	1.22	.81	.98
MgO	.38	.73	1.43	1.92	1.11	.88
Na_2O	2.19	.80	1.45	1.33	1.18	1.52
K_2O	1.61	.93	.83	1.60	1.84	2.26
H_2O	[1]4.63	[1]10.46	[1]10.79	[1]11.72	[2]6.98	[2]5.93
CO_2	.43	.30	.29	.39	.....	.....
C	.19	.34	.22	1.09	.....	.....
Totals	100.39	100.50	100.09	100.68	100.36	100.23

Of these analyses Nos. 1 and 2 are from the same vertical section, the former being four and one-half feet from the surface and the latter eight and one-half feet and in contact with the underlying limestone. Nos. 3 and 4 are related in the same way, the former being three feet from the surface and the latter four and one-half feet and lying in contact with the rock.[3] Nos. 5 and 6 are from the brickyard of John Grindell at Platteville.[4]

Thickness of the soils.

The thickness of the soils of the driftless area varies greatly. It is greater on the hill tops and in the bottoms of the valleys and less on the slopes. The following is an accurate statement concerning the average thickness of the soil:

[1] Contains H of organic matter. Dried at 100° C.

[2] Contains also some C.

[3] T. C. Chamberlin and R. D. Salisbury: Sixth Annual Report U. S. Geol. Survey, p. 250, 1885.

[4] E. R. Buckley: Wisconsin Geol. and Nat. Hist. Survey, Bull. vii, pt. i, p. 273, 1901.

"The following general averages are based on measurements which include the residuary earths and that portion of the residuary rock which is intermingled with them, but which do not include the disintegrating rock which underlies the clay but is not commingled with it. The average depth of the residuary material, thus defined, as shown by the eighteen hundred measurements, is 7.08 feet. The amount varies widely in different topographic situations. It is greater on ridges and in valleys than on slopes, and is deeper the wider the ridges and the valleys. Of about one thousand measurements on slopes, steep and gentle, the average depth is 4.61 feet. On ridges, not including broad tracts of upland, the average, as shown by three hundred and sixty measurements, is 8.06 feet. Two hundred and nineteen measurements on broad upland tracts give an average of 13.55 feet. The average for broad ravine bottoms, or short, wide valleys unoccupied by streams, is 6.93 feet, as indicated by one hundred and twenty-three measurements. The average of fifty-five valley measurements is 18.17 feet. In this last class are included only the measurements made in valleys which have a notable flat, and the average here given may not very well represent the average depth of loose material in such situations, since measurements in the large valleys, as those of the Mississippi, Wisconsin, and Pecatonica rivers, were rarely obtainable, but would have served to swell the average result. The extremes of depth are zero on the one hand and 70 feet on the other, the maximum being on upland. It is not certain that in this instance the excavation was not in a crevice. Measurements exceeding 25 feet are, in this topographic situation, exceedingly rare."[1]

Amount of rock represented by the soils.

When the chemical composition of the original rock is compared with the chemical composition of the soils derived from it and the thickness of these soils, it is readily seen that the amount of soil which is now present in any given locality is the

[1] T. C. Chamberlin and R. D. Salisbury: Op cit., p. 254.

equivalent of a very much greater thickness of rock,—just how great a thickness it is impossible to say without complete analyses, but a very good general estimate can be made.

The analyses given show that the carbonate of lime and magnesia have practically disappeared from the soil. In the original rock these carbonates make up probably 90 per cent. of the total. In some residual soils which have been carefully studied it has been found that over 97 per cent. of the original limestone has been removed in the process of weathering; in other words in such a case a present thickness of three feet of soil would represent an original thickness of 100 feet of rock.[1] In this district, assuming that 90 per cent. of the rock has been removed by weathering, a thickness of ten feet of soil would represent an original thickness of 100 feet of rock. The results of the numerous measurements already quoted show an average thickness of about thirteen and one-half feet on the broad uplands. It is thus clear that at least 100 feet of rock have disappeared slowly by weathering from this district.

Amount of erosion.

This brings us back, however, to another statement which was made on a previous page[2] regarding the amount of material which had been removed from this district since the formation of the peneplain. With the above facts concerning the soils in mind, we can easily add 100 feet to the 150 or 200 feet there mentioned, and thus have a layer 250 to 300 feet thick which has been removed from the whole district. Of course it is possible that some of this soil was formed at the time the peneplain originated, and how extensive the soil thus formed was, we cannot say. But it seems doubtful, however, that a large thickness of this old soil has continued to the present day. Moreover, it is extremely unlikely that none of the soil formed on these broad uplands has been removed by erosion; and, if the amount thus removed can be balanced against that formed by decay at

[1] G. P. Merrill: "Rocks, rock weathering and soils," p. 233, 1897.
[2] P. 12.

the time the peneplain originated, the above estimate of the amount of erosion in the district since the formation of the peneplain still stands.

If then at least 100 feet (the actual amount seems quite likely to be considerably greater than this) can be added to the amount of erosion accomplished directly by the streams, it will bring the surface of the original peneplain in general close to the top of the Galena limestone. In other words, it seems that, as far as the three counties here discussed are considered, the hard Galena limestone played an important part in determining the position of this peneplain. For it acted as a hard basement from above which were removed the much softer Hudson River shales. Thus, if it were not for other facts, there might be some doubt that the level upland plain is a true peneplain, but is more likely a structural plain. However, outside of the areas of these three counties, especially to the north and northeast, this peneplain, it is said, bevels other formations, and its true nature is thus evident.

Loess and alluvium.

It should be added that there are some soils in the district which are not of a residual character. Such are (1) the loess which is found on the uplands along the Mississippi valley, (2) the alluvium on many of the river bottoms, and (3) the overwash glacial deposits which are found along the Wisconsin and Mississippi rivers, but not along the smaller rivers. The two larger rivers head without the driftless area and thus brought down the drainage from the ice sheet, while the other rivers of the district head well within the driftless area and so were not carriers of glacial waters.

DRAINAGE.

The main stream of the district is the Mississippi, forming its western boundary, and its main tributary is the Wisconsin which forms the northern boundary of the district under consideration. These two trunk streams receive all the drainage of the region. The divide between the streams which flow north

into the Wisconsin and those flowing south into the Mississippi is along the Military ridge. This divide is only some fifteen miles south of the Wisconsin, so the northward flowing streams are much shorter and of much steeper gradient than the southward flowing ones. The important streams of the latter class are, from west to east, the Grant, Platte, Little Platte and Pecatonica rivers.

As the district has been so long subjected to erosion the streams have reached every part of it and the interstream areas are thus well drained, the ground-water on the uplands being a number of feet below the surface.

CHAPTER III.

GENERAL GEOLOGY.

The rocks of the lead and zinc district consist entirely of sedimentary deposits laid down in the early part of the Paleozoic era. No igneous and metamorphic rocks are exposed anywhere in the district, although such rocks exist below the base of the flat lying Paleozoic series and have been reached in a number of deep borings. To the north and northeast of the lead and zinc district these older rocks outcrop, first, in isolated areas, as for instance in the bluffs of quartzite about Baraboo and Devils Lake, and still further north in central and northern Wisconsin they form practically the whole surface. These underlying, igneous and metamorphic rocks are of an age far antedating the overlying sedimentary rocks. The older rocks were practically in their present position and condition long before the formation of the ore deposits.

The sedimentary rocks occurring in the lead and zinc district are readily separated into seven different formations. These are, in descending order, as follows:

(See plate II.)

Niagara limestone	**Silurian (or Upper Silurian)**
Hudson River shales	**Ordovician (or Lower Silurian)**
Galena limestone	
Trenton limestone	
St. Peter sandstone	
Lower Magnesian limestone	**Cambrian.**
Potsdam sandstone	

During the deposition of these rocks southwestern Wisconsin was covered by the sea, and land areas from which the clastic formations were derived existed to the north. The different

formations are essentially continuous one with the other, there being no marked unconformity in the whole series. There are, however, indications that part of the district, at least the part adjoining the shore line on the north, was at various times below the sea level and again above it, and the rapid changes from sandstone to limestone, and from limestone to sandstone, indicate changes of importance in the sea level. In addition to this certain facts have been brought forward to show that erosion valleys were formed in the surface of the Lower Magnesian limestone before the deposition of the overlying sandstone, and that these valleys were later filled by deposits of the St. Peter sandstone.[1]

The rocks of the district dip in general towards the southwest at a very low angle. There are, however, localities where this general southwesterly dip is interrupted by northerly and northeasterly dips, showing that the district has been slightly folded by a force acting from north to south or from northeast to southwest. At the same time, some of these irregularities in dip may be explained, not by deformation since the beds were deposited but by the deposition of sediment on an irregular sea bottom. This is especially the case in regard to the St. Peter sandstone which was deposited on the undulating surface of the Lower Magnesian limestone. Nevertheless, as will be noted in the description of the ore deposits, rock deformation in this district has been more prominent than is generally supposed.

The lead and zinc deposits of the district are not confined to any one particular horizon, but have been found from the Niagara limestone to the Potsdam sandstone; nevertheless, by far the larger number of these deposits, and in fact practically all of those yet discovered of economic importance, lie in the Galena limestone or towards the top of the underlying Trenton.

[1] This point was brought out by Professor E. C. Perisho, of the Platteville Normal School, in a paper read at the last meeting of the Wisconsin Academy of Sciences, Arts and Letters; in this paper it is also stated that "the present streams are now cutting out the old pre-St. Peter valleys,—thus making their valleys coincide with and follow the old erosion valleys."

POTSDAM SANDSTONE.

The lowest and oldest formation exposed in the district is a thick body of sandstone known as the Potsdam. Interbedded with this great sandstone formation are certain shaly and limy layers, but these make up only a small percentage of the total thickness. The Potsdam sandstone reaches a maximum thickness of about 1,000 feet, and the average thickness is a few hundred feet less than this. Within the lead and zinc district the total thickness of this sandstone is nowhere exposed; in fact, the exposures of this formation are confined to the valley of the Wisconsin and its immediate tributaries. The greatest thickness of the Potsdam exposed in the district is about 300 feet of the upper part of the formation. The sandstone is composed essentially of rounded grains of quartz, which as a rule are not firmly cemented; at the same time the whole formation averages harder and more enduring than the St. Peter sandstone. The Potsdam sandstone, being a coarse-grained rock which is not fully cemented, having the requisite inclination and being included between practically impervious beds, forms a very important source of water for artesian and deep wells.

LOWER MAGNESIAN LIMESTONE.

This formation, so named to distinguish it from the Galena and the Niagara, both of which are magnesian limestones or dolomites, immediately overlies the Potsdam sandstone. It consists of an impure, rough-weathering, fine, often brecciated dolomite. With it are considerable amounts of impurities, especially sand, clay and large quantities of flint. The latter material occurs in masses and layers of considerable size and frequently is extremely abundant in the soils derived from this formation. Not uncommonly small cavities exist in the limestone or in the masses of flint and these are lined with crystals of quartz, in fact, there are more crystals of quartz in this formation than in any others of the district, which are as a rule noticeably deficient in silica in crystallized forms. The Lower

Magnesian limestone varies in thickness from a maximum of about 250 feet to a minimum of approximately 100 feet. It is exposed along the Mississippi and the Wisconsin rivers and the tributaries of the latter, and has also been cut into by some of the southward flowing streams of the district, especially the Grant, the Platte and the East Pecatonica.

ST. PETER SANDSTONE.

This consist of nearly pure quartz sand containing very little foreign material. The quartz grains are water-worn and consequently well rounded, and as a rule are very poorly cemented, as a consequence of which the rock crumbles readily and is not commonly seen in solid exposure except where cut into by active streams or where protected by the cliffs of the overlying Trenton limestone. This sandstone varies in thickness from place to place and this variation is largely due to the undulating character of the immediately underlying rock,—the Lower Magnesian limestone.[1] The maximum thickness of the St. Peter in the lead and zinc district is approximately 150 feet and the minimum 50 feet, or perhaps even less. This sandstone formation, like the Potsdam sandstone, is an efficient carrier of artesian water. From the fact that it is cut into by streams so frequently in this district, it is not an important source for artesian wells, but it forms a favorable location for wells which are not flowing.

Unusual section at the top of the St. Peter.

At an excavation being made for a water reservoir on the bluffs just east of Prairie du Chien an interesting section is exposed showing the transition between the upper part of the St. Peter sandstone and the lower part of the Trenton limestone. The transition here is not as sudden as is usual and is described briefly in the next paragraph. As this section may soon be covered up it is thought best to reproduce it here.

[1] T. C. Chamberlin: Geol. of Wis., vol. i, pp. 138–140, 1883.

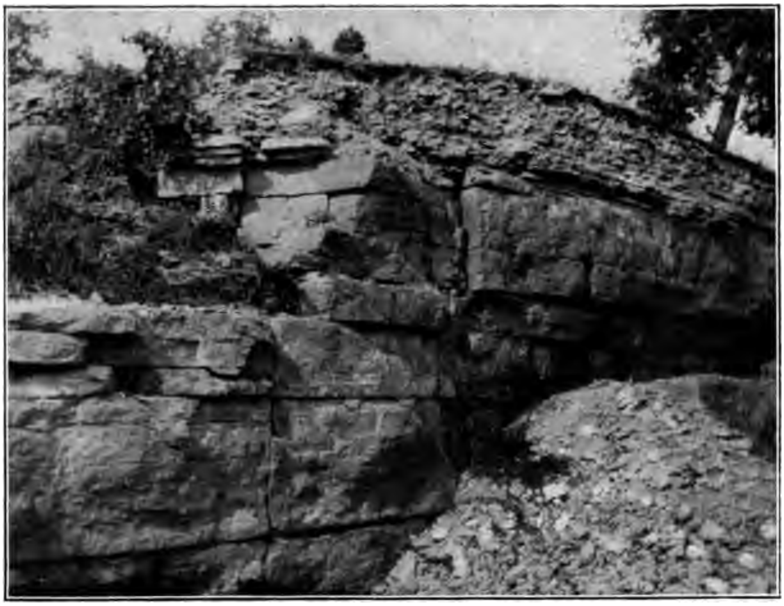

Fig. 1. Joint faces in buff limestone (lower part of the Trenton) in quarry on Little Platte river, west of Platteville. Limestone passing into soil above.

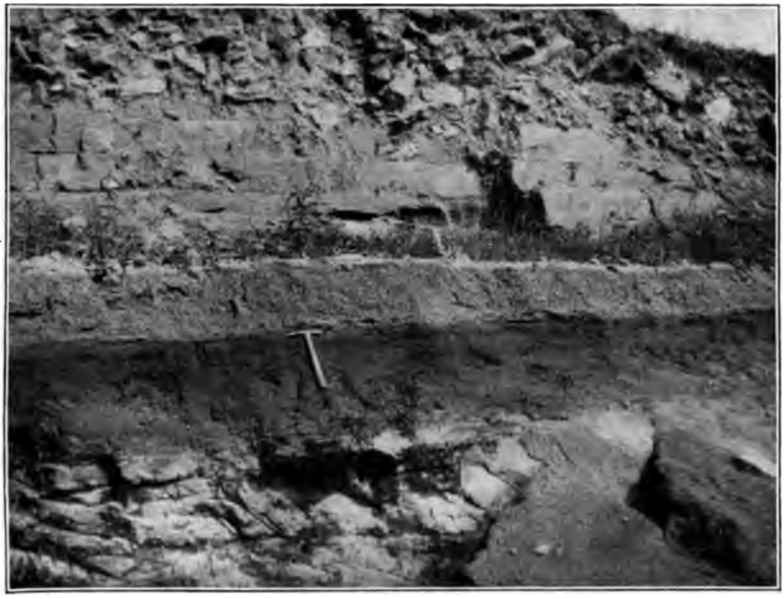

Fig. 2. Contact of St. Peter sandstone and Trenton limestone in quarry on Little Platte river, west of Platteville. The head of the hammer marks the contact; the upper *part of the sandstone is* [illegible] passing below into the almost white sandstone; the *first layer above han* [illegible] ale at the base of the Trenton; above this is the *buff limestone.*

10. Soil with fragments of limestone	5 feet.
9. Bluff limestone, or quarry rock of the Trenton, in heavy beds	2 feet.
8. Limestone like the last but in thin layers	2 feet.
7. Green glauconitic sandstone	2 inches.
6. Pure white sandstone	6 inches.
5. Yellowish brown limestone, fine grained and compact.	4 inches.
4. Pure white sandstone	3 ft., 6 in.
3. Gray brown limestone, similar to No. 5	1 foot.
2. Green glanconitic sandstone	5 inches.
1. Brown to white sandstone, sometimes very firmly cemented and appearing like quartzite. This is the top of the main mass of sandstone	6 feet.

TRENTON LIMESTONE.

The transition from the St. Peter to the next overlying formation is commonly very abrupt. The sandstone ends suddenly and is overlain by a bed of shale. (See plate II, figure 2.) This shale is usually blue in color and frequently contains a considerable admixture of sand. The shale layer averages about a foot in thickness, although sometimes being not more than half this, and at other times becoming three or four feet thick, and is succeeded by a well-marked limestone of the lower part of the Trenton. In thickness the Trenton varies from about 40 feet to 100 feet. It differs from the Lower Magnesion and the Galena limestones in being essentially a true limestone and not a dolomite or magnesian limestone, except in its lower part.

Local names have been given to different divisions of the Trenton limestone, although it is uncertain whether these divisions can be recognized throughout the district. The most common names are: the buff limestone, the blue limestone, the brown rock, the green rock, and the glass rock. The most constant and the most easily recognized of these divisions are the first, or buff limestone, and the last, or glass rock.

The buff limestone.

The buff limestone, or, as it is frequently called, the quarry rock, makes up the lower part, probably about the lower half,

of the Trenton formation. (See plate II, figures 1 and 2.) It is used throughout the lead and zinc district as a building stone and in fact is the chief source of building material in the whole district. The name buff limestone was applied because of the color of the rock, but in nearly all the quarries away from the surface and the joints,—that is, in positions where the oxidizing effect of the surface waters has not been experienced,—the limestone instead of being buff in color is of a grayish blue, and this latter is the natural, unaltered color of the rock.

The glass rock.

The glass rock belongs near the top of the Trenton limestone. This term has been applied to a number of varieties of limestone in this general horizon. It may be said that the name is used for very fine-grained, compact and hard beds of limestone which occur near the top of the Trenton. This is about as accurate a general definition of the term as can be given. There is, however, one particular phase of this rock which may be called the typical glass rock and which is apparently the rock to which the name was first applied. This is a very fine-grained, very compact limestone which breaks with a conchoidal fracture and which when fresh is of a light brown or chocolate color. On exposure to the air, however, this color changes to a bluish gray. This phase of the glass rock is found in many places throughout the western two-thirds of the lead and zinc district. It usually occurs in thin beds and in some places, especially at Platteville, is an important building material, the Normal School building at this place and one of the High School buildings being constructed almost entirely of this rock. The fact that it does not occur in thicker beds prevents its universal use as a building stone. Very frequently this glass rock is packed full of fossils. It is a comparatively pure limestone containing only a small amount of magnesia, the chief impurities being silica and clay. The composition of this rock is shown by the accompanying analysis:[1]

[1] Geol. of Wis., vol. ii, p. 681, 1877.

Analysis of the glass rock.

Silica, SiO_2	6.160
Alumina, Al_2O_3	2.260
Sesquioxide of iron, Fe_2O_3	.950
Carbonate of lime, $CaCO_3$	85.540
Carbonate of magnesia, $MgCO_3$	3.980
Water, H_2O	.930
Phosphoric anhydride, P_2O_5	.055
Total	99.875

GALENA LIMESTONE.

This is the main ore-bearing formation of the district and appears as a granular, crystalline, porous, and at times sandy (i. e., limestone sand and not quartz sand) rock, which by weathering is reduced to irregular and ragged outlines. Its color is a light yellowish gray, sometimes buff, but when it has not been exposed to weathering and when found below the water level it is usually of a light bluish gray color. Frequently thin seams of clayey material occur separating the layers of this limestone. It contains a large amount of flints, although this material is not as abundant and is not in as large masses as when found in the Lower Magnesian limestone. These flints are frequently in rough layers and at times may have a definite relation to the ore deposits. The flints are found mostly in the lower half of the formation; in fact, exposures of the upper half of the formation are common in which no flints are to be seen. Galena limestone is the typical country rock of the district, being the surface rock over probably three-fourths of the area and being frequently exposed along the streams and road cuttings. This limestone is about 250 feet in thickness.

In composition the Galena limestone is a dolomite and it thus differs markedly from the underlying Trenton. An analysis of the Galena limestone has already been given on a previous page.[1] The cause of the dolomitic constitution of this

[1] P. 15. —

limestone can not be fully discussed here. As far as known at present this dolomitic character extends from the top to the bottom of the Galena limestone in the lead and zinc district of Wisconsin, but in Dubuque county, Iowa, it is stated that the dolomitization does not extend to any definite depth or to any definite horizon, in some places extending much deeper into the formation than in others.[1] To the east and to the north in the upper Mississippi valley, without the lead and zinc district, it has been found impossible to separate the Trenton and Galena, and they have been grouped into one formation which has received the name Galena–Trenton, or simply Trenton. While the separation between the two formations is not, and apparently cannot be, definitely made in many districts, it seems to the writer very clear that the two formations can be separated easily and distinctly within the lead and zinc district of Wisconsin, and this subject will be considered in some detail under the next heading.

Separation between the Trenton and Galena.

As has already been stated, the writer believes that these two formations can be easily and definitely distinguished within the lead and zinc districts of Wisconsin, and in this belief he agrees apparently with others who have been working in the district. As this matter of the separation of the two formations becomes an important one in the mining geology of the district, and as the subject has not heretofore received very much attention, it is thought best to devote some little space to this phase of the geology. Recognizing at once that nothing like complete information regarding the chemical composition of the limestones of the district is at hand, it still seems that the separation between these two formations can be made out by lithological and stratigraphical means, and to this end there follows a series of sections taken across the transition or the junction between these two formations. In these sections it should be stated that the measurements are only approxi-

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[1] Samuel Calvin and H. F. Bain: "Geology of Dubuque Co.," Ia. *Geol. Survey,* vol. x, pp. 407-411, 1900.

mately acurate, in fact, they could not be accurate because the different beds along this contact vary quite markedly in thickness from place to place and even within a distance of only a few feet.

I. Section at the Graham mine. This mine is situated about two miles west of Platteville and just east of the Little Platte river (Sec. 18, T. 3 N., R. 1 W.). Here the following section can be made out:

11. Yellow-gray limestone, typical Galena	10 feet.
10. Blue shale, not seen but reported by the miners	1 ft., 6 in.
9. Yellow-gray limestone, similar to No. 11 above	8 feet.
8. Thin beds of blue limestone, separated by narrow bands of oil rock. Frequently this blue limestone is turning brown along the cracks and edegs of the bands. This is the chief ore horizon, the blende and galena being disseminated through these blue limestone bands	4 feet.
7. Oil rock mixed with sandy shale and some thin bands of blue limestone which carries ore in the same manner as No. 8	8 inches.
6. *The main oil rock*, containing ore also	1 ft., 6 in.
5. Blue shale	1 ft., 6 in.
4. Oil rock	3 inches.
3. A soft yellow to white clay, called "pipe clay"	1 foot.
2. Black carbonaceous shale or slate	2 inches.
1. Buff limestone	1 foot.

Below this are some other exposures of limestone similar to No. 1, but no uniform layers of typical glass rock were found here although they occur in several places within the distance of a mile to the south on the east side of the Little Platte river.

II. Section at the Phillips and Rice mine. At this mine, which is about one-fourth of a mile west of the Graham mine, but on the west side of the Little Platte river, is the following section:

4. Ordinary buff Galena limestone	3 feet.
3. Thin beds of limestone, some of which look much like the typical glass rock, separated by thin bands of oil rock	5 feet.
2. *The main oil rock*	1 foot.
1. Blue shale	1 foot.

III. Section at the Tippecanoe mine. At this mine, which is about a mile west of the Graham and the Phillips and Rice mines, the following section can be seen along the opening to a tunnel:

5. Thin beds of blue limestone and narrow beds of oil rock; this is the ore horizon	5 feet.
4. *The main oil rock*	1 foot.
3. Blue shale; in places some of this is closely like the oil rock and at the bottom there is a fairly continuous layer of blue to gray-yellow soft clay	4 feet.
2. Black carbonaceous shale or slate	2 inches.
1. Hard blue limestone	3 feet.

IV. Section at a quarry west of Platteville. At a quarry on the west side of the Little Platte river (N. E. 1/4 Sec. 8, T. 3 N., R. 1 W) is an extensive exposure of the upper part of the Trenton and the lower part of the Galena. Here the following section was observed:

11. Blue limestone with some thin shale bands in its upper part, becoming rather coarse, characteristic yellow Galena limestone; contains no noticeable fossils	12 feet.
10. Blue sandy shale, sandy character probably being due to decaying limestone	6 inches.
9. Blue limestone and thin bands of oil rock, also some beds of limestone which are very similar to the typical glass rock. Contains few fossils in its upper part, but in its lower part is highly fossiliferous. All the beds below this, excepting part of the lowest one, are commonly highly fossiliferous	6 feet.
8. Brown or chocolate colored shale, regarded as *the oil rock*	2 inches.
7. Blue limestone and limestone very similar to glass rock but in irregular beds	7 feet.
6. Blue shale	10 inches.
5. Blue limestone with layers of blue shale and some layers like glass rock	3 feet.
4. White to yellow-brown clay or shale	6 inches.
3. Blue limestone with narrow blue shale bands	1 ft., 6 in.
2. Glass rock, typical, in six inch beds with somewhat shaly partings. The upper layer of this glass rock frequently has a peculiar mottled appearance	2 ft., 9 in.

1. Hard blue limestone similar to the quarry rock or the buff rock; occurs in thick beds, but on weathering breaks up into thin layers .... 9 feet.

V. Section at the Enterprise mine. At the Enterprise mine at Platteville near the bottom of the shaft the following section occurs:

4. Hard blue or grayish blue limestone, the Galena.
3. Thin beds of hard blue limestone with narrow bands of oil rock .... 7 feet.
2. *Oil rock* .... 1 ft., 6 in.
1. Hard blue limestone .... 1 foot.

VI. Section at the Gritty Six mine. At the Gritty Six mine (S. W. 1/4 Sec. 21, T. 2 N., R. 1 E.) southwest of Meekers Grove, the following section is shown at the bottom of the mine:

4. Blue limestone, Galena.
3. Layers of yellow and blue limestone with narrow bands of oil rock and some yellow sandy shale.... 4 feet.
2. *The main oil rock* .... 2 feet.
1. Blue shale and blue limestone, the shale being rather hard . ... 2 feet.

VII. Section at the Kennedy mine near Hazel Green. At the Kennedy mine (S. W. 1/4 Sec. 29, T. 1 N., R. 1 E.) the following section is seen at the bottom of the shaft and along a level running west from the shaft:

7. Blue Galena Limestone.
6. Bands of highly fossiliferous limestone, some of which is typical glass rock, with narrow bands of typical oil rock .... 8 feet.
5. *The main oil rock* .... 2 feet.
4. Blue shale, rather soft and almost like clay in places 10 inches.
3. Oil rock .... 10 inches.
2. Shale similar to No. 4 .... 10 inches.
1. Typical glass rock .... 2 feet.

VIII. Section at Mineral Point. At Mineral Point some dry bone mining is going on on the land of Mr. W. S. Ross (S. W. 1/4 Sec. 31, T. 5 N., R. 3 E.). Here the following section is made out near the bottom of one of the shafts:

7. Yellow Galena limestone.	
6. Thin layers of limestone full of fossils and much like typical glass rock; thin seams of oil rock	4 feet.
5. *Decaying oil rock*	6 inches.
4. Gray limestone, compact, and looking somewhat like glass rock but not typical	9 feet.
3. Decaying and sandy limestone with 4 to 8 inches at the bottom of rock closely like oil rock.............	2 ft., 6 in.
2. Fossiliferous limestone closely like typical glass rock	1 foot.
1. Decayed sandy rock and clayey material	9 inches.

This section is above the water level and consequently the rocks are mostly decayed and do not show their customary condition.

IX. Section at the Penitentiary mine. At this mine, just south of Mifflin, water makes it impossible to get the complete section, but the following is shown:

4. Gray Galena limestone.	
3. Sandy *oil rock* with some bands of limestone	4 feet.
2. Blue clay	8 inches.
1. Hard limestone called glass rock but not like the typical glass rock	4 feet.

There is said to be a greater thickness of glass rock here, and below that it is stated that there is a layer of black slate or shale 18 inches in thickness.

X. Section at the Ellsworth mine. At the Ellsworth mine (N. E. 1/4 Sec. 29, T. 5 N., R. 1 E.), west of Mifflin, the general section is as follows:

5. Hard gray Galena limestone.	
4. Thin layers of limestone with fossils and narrow seams of oil rock. This limestone is at times very similar to the typical glass rock...................	7 feet.
3. *Oil rock*, which is here called "liner"	1 ft., 6 in.
2. Blue clay	2 inches.
1. Hard blue limestone	

XI. Section at the Glanville mine. At the Glanville mine, near Linden, is the following section:

6. Gray Galena limestone	
5. Sandy limestone with some thin bands of oil rock; there is no glass rock or rock like glass rock here..	8 feet.

4. *Oil rock*, rather hard and sandy	2 feet.
3. Blue shale or clay	3 inches.
2. Hard brownish compact limestone. This limestone is here called glass rock but it is coarser grained than the typical glass rock and does not have the conchoidal fracture	8 feet.
1. Bluish clay with narrow seams of oil rock	6 inches.

Below this it is reported that there is a hard blue limestone.

XII. Section at the Kennedy mine at Highland. At the Kennedy mine, just north of Highland, is the following section:

7. Hard Galena limestone	15 feet.
6. Bands of hard gray limestone with thin seams of rock which resembles oil rock, but harder than customary. This is called the lower opening	6 feet.
5. *Oil rock*, which is here more compact and harder than usual	1 foot.
4. Gray to yellow soft clay	6 inches.
3. Very hard, fine grained gray limestone. This is called the glass rock opening, but the rock is not like the typical glass rock	4 feet.
2. Oil rock	2 inches.
1. Hard limestone.	

XIII. Section at the Little Giant mine. At the Little Giant mine (S. ½ Sec. 4, T. 1 N., R. 2 E.), west of Shullsburg, a shaft has been put down through the oil rock, and here the following section can be made out:

6. Yellow decayed limestone	1 foot.
5. Soft sandy material, *oil rock* and soft yellow sandy clay confused, with the oil rock mainly in the lower half	3 ft., 6 in.
4. Blue shale	2 feet.
3. Blue shale with thin layers of oil rock	1 foot.
2. Very hard, compact, fine-grained limestone resembling, but coarser than, the typical glass rock	6 feet.
1. Same as the last but holding small flats and fractures which are filled with ore	7 feet.

Below this bed, twenty-two feet of rock similar to Nos. 1 and 2, with two or three narrow beds of shale, are said to have been

penetrated. In the tunnel of the Galena level, which is a short distance to the west, several feet of rock similar to this,—i. e., similar to Nos. 1 and 2,—are found above the oil rock.

XIV. Section at Darlington. In a quarry on the south side of the Pecatonica river at Darlington, there is a fine exposure running from near the base of the Trenton up into the Galena. The section here, roughly measured, is as follows:

6. Galena limestone in thick beds and holding one thin shale layer	20 feet.
5. Limestone similar to No. 2 below, in thin beds	4 feet.
4. *Oil rock*, inconspicuous	2 inches.
3. Thin beds of limestone similar to No. 2 below	4 feet.
2. Hard, fine grained, brown limestone looking somewhat like glass rock but coarser, lighter colored and without the conchoidal fracture. This rock is here burned for lime	10 feet.
1. Heavy bedded buff limestone or quarry rock. Where unweathered this is blue or gray-blue in color instead of buff	35 feet.

The oil rock. Aside from the glass rock, which has already been mentioned, the oil rock plays an important part in all of the above sections. This oil rock is a compact, very finely laminated, soft shale which varies in color from a very light yellowish gray to a dark chocolate brown color, and even becomes perfectly black in places. The dark chocolate brown color is the customary one. It contains a considerable percentage of carbonaceous matter, which is evidenced sometimes by the peculiar petroleum odor which the rock gives off, especially when heated. When dry, particles of this rock will usually burn with a thick smoky flame. Partial analyses of this rock show the following composition:[1]

	Carbonaceous matter.	Carbonic acid.	Water.
1	43.60	.88	.30
2	18.31	1.85	.40
3	15.76	.60	.32

[1]Moses Strong: "Geology and topography of the lead region," Geol. *of Wis., vol. ii, pp.* 680–681, 1887.

Of the above analyses, No. 1 is from the Oakland level in the S. W. ¼ of Sec. 5, T. 1 N., R. 2 E., near Shullsburg. No. 2 is from the Silverthorn mine in N. E. ¼ Sec. 31, T. 2 N., R. 2 E.,and No. 3 is from the same locality as No. 2.

General section and résumé. Summing up the foregoing sections it will be found that the following represents the general average:

Generalized section between the Trenton and Galena.

5. Galena limestone.
4. Thin beds of limestone, at times resembling or similar to the glass rock, and at times a soft blue limestone, with thin seams of oil rock.
3. Oil rock.
2. Blue shale or clay.
1. Typical glass rock or rock resembling glass rock.

Perhaps from a strictly scientific point of view the lower limit of the Galena limestone should be drawn at the bottom of No. 5 of the above section. Immediately below this comes in quite frequently a rock which much resembles the typical glass rock, which is very frequently highly fossiliferous, and which appears to be a true limestone rather than a dolomite. In all of these three respects this rock differs markedly from the Galena above. At the same time this band of rock which is described under No. 4 of the above section is not always present, nor when present can it always be recognized. Moreover, the oil rock seems to be the only layer of the whole series which is present and constant in all sections.[1] It has peculiar and marked characteristics of its own. It is very easily identified and is a layer which is known to all the miners of the district,—in fact, generally in sinking a shaft when the oil rock is struck work is discontinued. For these reasons the writer has seen fit in the descriptions in this report to make the oil rock the dividing line between the Galena and the Trenton; and throughout this report this division between the two formations is maintained,—i. e., the Galena limestone is delimited

[1] In the foregoing sections this oil rock, i. e., the base of the Galena as here defined, is in italics.

below by the base of the main oil rock horizon. This conclusion is reached from a careful study of a number of sections, from conversation with different mining men, and from a desire to have established some definite and precise horizon by which the Trenton could be readily separated from the Galena.

In this same connection it is well to note that Moses Strong[1] came to a similar conclusion concerning the division between the Trenton and the Galena limestones. His statements are as follows:

"The Blue is remarkable as being the purest limestone in the lead region, and the nearest approach to the Trenton limestone of the eastern states, both in its lithological and paleontological characteristics. A very noticeable feature is its marked division into two parts; one very heavy-bedded, in layers of two or three feet thick, known as the glass rock, which constitutes the lower half; and the other, thin-bedded, in layers of two or three inches, graduating sometimes without much change into the thin-bedded Galena limestone above. It is at this point that the stratum of carbonaceous shale occurs, which is the line of demarcation between the Blue and Galena limestones, and as such ,*is an unfailing guide.* (The italics are the writer's.) It varies very much in its thickness, being from a quarter of an inch to a foot or more, but wherever a good exposure of the two formations is seen, it has uniformly been found."

HUDSON RIVER SHALES.

Overlying the Galena limestone is a formation composed largely of bluish to greenish shales, with occasional thin bands of limestone. On account of their soft nature these shales are very easily eroded and are seldom exposed. They are found usually in the vicinity of the mounds. As a rock formation the Hudson River shales are not of great importance in this district and no ore bodies are known to be contained in them, but their influence in the formation of ore deposits will be spoken of later.

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[1] *Op. cit., p.* 680.

NIAGARA LIMESTONE.

This occurs as the capping to the mounds. To the east and south of the lead and zinc district the Niagara limestone covers large tracts of country, and the small remnants of it which are found in the lead and zinc region are without doubt all that is now left of a once extensive layer of this limestone which covered practically the whole district. This limestone, like the Lower Magnesian and the Galena, is a dolomite and contains also a large number of flints, in fact, as far as lithology is concerned these three dolomitic limestone formations at times quite closely resemble each other. At the west Blue mound the upper part of the Niagara limestone is a highly siliceous, cherty or quartzite-like layer.[1]

Only small amounts of lead and zinc have been reported from the Niagara limestone.

LATER FORMATIONS.

After the deposition of the Niagara limestone there is no positive evidence that other stratified rocks were laid down in this district. It is of course possible that the region was still below sea level as late as the end of the Paleozoic time and received the deposits of Devonian and Carboniferous age. No remnants of these rocks are found anywhere in the district and it seems rather improbable that the Carboniferous rocks extended this far north between the Mississippi river and lake Michigan. There is, however, more possibility that the Devonian may have once covered this territory, for the fact that rocks of this age were more extensive than has heretofore been supposed is shown by the finding of Devonian fossils in cracks in the Niagara limestone of northeastern Illinois.[2]

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[1] Moses Strong: "Geology and topography of the lead region," Geol. of Wis., vol. ii, p. 667.

G. D. Hubbard: "The Blue Mound Quartzite," Am. Geol., vol. xxvi, pp. 163–168, 1900.

[2] Stuart Weller: "A peculiar Devonian deposit in northern Illinois," Jour. of Geol., vol. vii., pp. 483–488, 1899.

Rocks of Cretaceous age are found to the west both in Iowa and Minnesota. During Cretaceous times it is thought that a large part of Wisconsin and adjacent districts were reduced by erosion practically to the level of the sea, but it has not yet been proved that the Cretaceous ocean extended as far east as southwestern Wisconsin; at the same time it is not improbable that outliers of Cretaceous age may yet be found in this part of the state. Of rocks later than the Cretaceous age, we have no knowledge in this immediate district; in fact, deposits of Tertiary age are known no nearer than Missouri and southern Illinois and the Great Plains district. At the same time there are certain isolated deposits of gravel which have been found in Illinois and at one or two points in Wisconsin which possibly may be regarded as the remnants of a once extensive deposit of Tertiary gravel.[1]

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[1] R. D. Salisbury: "Pre-Glacial gravels on the quartzite range near Baraboo, Wisconsin," Jour. Geol., vol. iii, pp. 655–667, 1895.

CHAPTER IV.

THE ORES AND ASSOCIATED MINERALS.

The minerals of the lead and zinc district of Wisconsin are not as numerous, so far as species go, as one would naturally expect in a mining district; in fact, the minerals which are here to be ordinarily seen are confined to a few of the commoner forms. The most important minerals are galenite, sphalerite, smithsonite, marcasite and calcite. These are by far the most abundant, most noticeable and most important. A number of other minerals, found associated with these, are of considerable interest and importance in a study of the ore deposits themselves.

THE ORES.

Lead ores.

Galenite. Also known as galena, lead sulphide and usually called by the miners "mineral." In chemical composition it is sulphide of lead, and when pure contains 86.6 per cent. of metallic lead. Galenite usually occurs in the form of crystals which are either cubes or less commonly octahedrons, or a combination of these two forms. When the mineral is in large crystals it is frequently called "cog mineral," and when in smaller ones, especially when disseminated through the rock, it is called "dice mineral," by the miners. A large irregular mass is sometimes known as "chunk mineral," and when this substance ocurs as thin layers in narrow fissures, it is called "sheet mineral." Galenite also occurs in a peculiar reticulated form, when it assumes the shape of various tree-like branches.

The sulphide of lead is the original lead mineral of the district. It is also the only lead ore which occurs in sufficient quantity to be mined. Unlike the ordinary galena found in most mining districts, the percentage of silver in the Upper Mississippi valley galena is small,—usually so small that it cannot be economically extracted.

Cerussite. Also known as lead carbonate and white lead ore. Chemically it is a carbonate of lead. It occurs in small amounts, usually as little crystals attached to the large crystals of galenite, or as a white to yellow powder-like coating on the galena crystals. The latter occurrence is more common near the surface of the ground. Cerussite is not one of the original minerals of the district, but is formed from galena in the belt of oxidation.

Anglesite. This is lead sulphate and is also a secondary mineral formed from galenite. It is mentioned in the reports as of rare occurrence, and an examination of some of this material from Mineral Point shows that the so-called anglesite is really selenite or gypsum.[1] In fact, it may be questioned whether this mineral exists in southwestern Wisconsin; at the same time there is no apparent reason why it should not occur.

Zinc ores.

Sphalerite. Known also as zinc blende, zinc sulphide and by the miners commonly called "black jack" or simply "jack." Chemically this is a sulphide of zinc, containing when pure 67 per cent. of metallic zinc. This is by far the most important ore of the district and is the original zinc mineral. It is found commonly below the level of groundwater and so was not discovered in the early explorations of the district. It varies in color from a light straw-yellow, through brown to jet black, the black color being due to impurities, especially iron. In some cases, especially in soft clays, sphalerite occurs in aggre-

[1] W. H. Hobbs: "A contribution to the mineralogy of Wisconsin." Bulletin of the University of Wisconsin, Science Series, vol. i, pp. 135–136, 1895. In this paper are descriptions of a number of the minerals of the lead and zinc district.

gations of small crystals with a berry-like shape, and this has been designated as "strawberry jack."

Smithsonite. Also known as zinc carbonate and by the miners called "dry-bone." Chemically this is a carbonate of zinc which when pure contains 52 per cent. of metallic zinc. All the smithsonite of the district occurs as an alteration product of sphalerite; it is thus a secondary mineral which has been formed in the belt of oxidation While sphalerite is more important as an ore, large amounts of smithsonite are still mined. This carbonate of zinc usually occurs as a porous material occupying the position of the original sphalerite. At other times it forms thin coats or crusts on the rock and especially on calcite crystals, and not uncommonly the calcite is found to be replaced by a porous mass of smithsonite. Near the level of ground water it is very frequently possible to find specimens which show beautifully the alterations from sphalerite to smithsonite; in such cases the inside of a mass of smithsonite will be found to be made up entirely or partially of unaltered zinc sulphide. (See Fig. 7, p. 75.) This ore of zinc is not used in the production of spelter, but all of it goes into zinc white, which is used as a base for paints.

Hydrozincite. This is known as zinc bloom and is a hydrocarbonate of zinc. When pure it contains 60 per cent. of metallic zinc. Hydrozincite is intimately associated with smithsonite and it is sometimes difficult to distinguish one from the other; in fact, this mineral is rarely recognized in this district, and no definite statement can here be made as to its occurrence. It differs from smithsonite in containing water as an essential constituent.

Calamine is a hydrous silicate of zinc and, while common in some zinc districts, has not, to the writer's knowledge, been reported from southwestern Wisconsin.

Other ores.

Iron ores. These exist in considerable abundance but are not of economic importance, as far as this district is concerned,

with the exception of the iron sulphide (pyrite and marcasite) which is used in the manufacture of sulphuric acid.

Pyrite is known also as iron pyrites, mundic, fool's gold, and by the miners is called "sulphur." Chemically this is sulphide of iron, containing 46.7 per cent. of iron and 53.3 per cent. of sulphur. Pyrite occurs frequently in cubes and in combinations of cubes and octahedrons, and in pentagonal dodecahedrons; very commonly the faces of the cubes are striated. Pyrite is throughout the district intimately associated with the sphalerite and with the galenite below the belt of oxidation. It is not so common in this district as the next mineral (marcasite) and these two (and probably a small amount of iron carbonate,—siderite) are the original iron minerals of the district.

Marcasite is known as white iron pyrites and is also called "sulphur" by the miners. It is of the same chemical composition as the pyrite, but its color is a little paler and it decomposes more readily on exposure to the atmosphere. Marcasite forms the important iron mineral of the district. It is much more abundant than the pyrite, and in the remainder of this report all of the iron sulphide will be spoken of as marcasite.

Limonite is a hydrous oxide of iron and is known as brown hematite, yellow ocher, and by the miners it is frequently called "iron." Chemically it is a compound of iron, oxygen and water. It exists in large amounts and is a product of the alteration of marcasite in the belt of oxidation.

Hematite is an oxide of iron and is known as red iron ore and red ocher. It is not as common as limonite, but the red clays which occur so abundantly with the lead ores owe their color mainly to the presence of hematite.

Melanterite is known as copperas, iron vitriol and green vitriol. Chemically this is a sulphate of iron. This is frequently formed in the decomposition of the sulphide of iron (marcasite), and very commonly heaps of this latter mineral are found covered with a white coating which is melanterite. This material, however, is soon dissolved and carried away and does not accumulate in large amounts.

Copper ores. While ores of copper are not abundant, they occur in places and have at times proved of economic importance. The original copper ore is chalcopyrite (a sulphide of copper and iron), and quite probably oxide of copper also occurs. In the belt of oxidation the copper ores have been altered to the green copper carbonate (malachite) and also less frequently to the blue copper carbonate (azurite).

Manganese ores. It is probable that some original sulphide of manganese exists in the district, from which has been derived the secondary mineral known as wad or black oxide of manganese. This latter is not common, but occurs at times and is called black ocher.

ASSOCIATED MINERALS.

Calcite. This is known as calcspar or spar and by the miners is usually designated as "tiff." Chemically it is a carbonate of lime. It is a soft mineral, cleaves very easily into rhomb-shaped fragments, and when pure is transparent and colorless. It is perhaps the most common mineral, at least the most noticeable one, in the district. It is almost always associated with the lead and zinc ores below the level of ground water, and in most cases was deposited after these ores. Its common mode of occurrence is as a lining to the cavities, or as a filling of those cavities, which contain the metallic sulphides along the walls.

Dolomite. This is a carbonate of lime and magnesia. In general features it resembles calcite, but does not occur commonly in large crystals. In fact, dolomite, notwithstanding its great abundance as a constituent of the galena limestone, is comparatively rare in the crystal form or anywhere outside of the mass of the rock.

Selenite. This is known as gypsum and as plaster. It is a hydrous sulphate of lime and is not common in this district. It has been reported from a few places, as Mineral Point, and Mr. G. S. Rice has shown the writer small specimens of this mineral from Potosi. The fact that gypsum has been mistaken for anglesite, has already been mentioned under the description of that mineral.[1]

[1] *P. 40.*

Barite. This is known as heavy spar; it is a sulphate of barium and on account of its high specific gravity it is sometimes difficult to separate it in milling from sphalerite, especially in certain localities where it is found intimately associated with this zinc ore. Barite appears to prevail in the vicinity of the oil rock and most commonly occurs as masses of radiating crystals in this rock. It is common at the Raisbeck mine near Meekers Grove, and has been found in the oil rock in the Enterprise mine at Platteville.

Quartz. This is pure silica, the substance which makes up ordinary sandstone. In the lead and zinc district quartz is mainly found in the form of flint which is abundant in the Galena limestone and also in the Niagara and the Lower Magnesian limestones. Notwithstanding the large amount of silica in the ore-bearing rocks, it is rarely found crystallized, except in cavities in the Lower Magnesian limestone, and here the crystals are commonly of small size.

Sulphur. Native sulphur, though not abundant, is occasionally found in the lead region in the pulverulent or minutely crystalline form in crevices or small cavities in the mines. It is undoubtedly due to the decomposition of the iron sulphides, pyrite and marcasite.[1]

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[1] T. C. Chamberlin: Geol. of Wis., vol. iv, p. 393, 1882.

CHAPTER V.

OUTLINE OF THE GENESIS OF ORE DEPOSITS.

All metalliferous deposits are separable into three classes, which are: (1) those which owe their origin to concentration in molten rocks, as some bodies of magnetic iron ore; (2) those which are deposited by the processes of sedimentation, such as placer gold deposits; (3) those which are deposited by circulating underground waters. To these might be added certain ores which may owe their origin to sublimation, i. e. to deposition from vapors. By far the larger number of all ore deposits known to mankind belong to this third division,—those which owe their origin to circulating underground waters,—and it is to this class of deposits that every one familiar with the subject will refer the lead and zinc ores of southwestern Wiscosin. It is proposed in this chapter to outline briefly the method of formation of this third class of ore deposits with special reference to those of the district under consideration. In this account an attempt will be made to present an outline of the modern theory of ore deposits, following especially the work of Van Hise.[1]

ZONES OF THE EARTH'S CRUST.

The crust of the earth may be divided into three zones. These are, from the surface inward: (1) the zone of rock fracture, (2) the zone of rock fracture and rock flowage, and (3) the zone of rock flowage. The deepest of these zones, or the zone of rock

[1] "Some principles controlling the deposition of ores," Trans. Amer. Inst. Mining Eng., vol. xxx, pp. 27-177, 1901.

flowage, is that in which the pressure is so great that, when rocks are deformed, instead of breaking they respond to this deformation by flowing. In this zone there are no cavities,—at least none of appreciable size,—and if a cavity were to be formed it would soon be filled by the inflowing of the rock from the walls. All rocks, even the hardest, when put under sufficient pressure,—pressure that is greater than the ultimate strength of the rock,—may be made to flow. Of course the amount of pressure necessary to make some rocks respond to deformation by flowage is very much less than that required by others. Thus a weak rock, such as shale, could be made to flow at a much higher position in the earth's crust than a much stronger rock, such as a granite. Below a depth of about 10,000 meters the pressure is sufficient to crush the strongest rocks, and so this zone of flowage comes to within this distance of the earth's surface. When, however, the influence of moisture and heat (with increasing pressure) is taken into consideration, it seems very probable that the zone of flowage comes much nearer the surface than 10,000 meters.

Above the zone of flowage, which is that zone in which all rocks will flow when deformed, is another zone which is called the zone of combined fracture and flowage, where certain rocks will flow when deformed rapidly, while others,—the more brittle ones,—will fracture. In such a case cavities will not occur in the less brittle rocks, while cavities may exist in the more brittle ones.

In the outer zone of the earth's crust, i. e. the zone of rock fracture, rocks, when rapidly deformed, respond by fracturing. In some cases, especially when the deformation is exceedingly slow, rocks will bend rather than break, and this matter of time is an important element in all the movements to which the rocks of the earth's crust are subjected. Nevertheless, many of the so-called folds or bends in rocks, which take place in the zone of fracture, are really due to a great number of small breaks. In this zone of fracture fissures, or cavities, of various kinds will be developed in the rocks. The most important of these are *those which are* known as fault planes, joint planes and planes

of rupture due to the differential movement of one bed upon another. It is only within this outer zone of the earth's crust that there is a free circulation of water, and so it is only within this zone that the main ore deposits occur. The rocks of the lead and zinc district of southwestern Wisconsin have never been buried deep enough to have gotten out of this zone of fracture, and the larger cavities which occur in these rocks, especially in the more brittle ones, such as the limestones, are fractures produced by the deformation of the rocks. Of course, the cavities, or openings, as they now exist in these rocks have in many cases been enlarged by solution. While the limestones have in most cases responded to deformation by fracturing, some of the softer beds, such as the shales and clays, have responded to the same deformation by bending and not by the production of cracks or fissures.

THE GENERAL CIRCULATION OF WATER.

The water which falls from the clouds upon the land may be separated into three parts: (1) that which is soon evaporated and returns to the sky; (2) that which flows off the surface of the ground, forming streams, lakes and oceans, and which is eventually subjected to evaporation; (3) that which sinks into the ground.

This last part, i. e. that which enters the ground, is the water which is of importance in the formation of ore deposits.[1] Seeping into the ground this water flows in very tortuous and complicated channels, but is almost constantly in motion, though that motion may be slow,—passing from areas of high pressure to those of lower pressure. The general law of underground circulation is that the water enters the ground at higher levels and emerges again, after a long or short journey, at lower levels, the result being that the circulation of this underground water, while not as apparent and not as marked as the circulation of the

[1] Some part of the water which enters the ground is soon brought to the surface again by capillarity and by vegetation and so does not enter into the formation of ore deposits.

water in the atmosphere and on the surface of the earth, is still just as important and just as real. The result is that the water which enters the outer zone of the earth's crust, after a long or short journey and a long or short time, returns to the surface, emerging in the form of springs or wells, or enters the rivers, lakes and oceans at or beneath their surface.

The water, seeping down from the earth's surface through the rocks, finally comes to a point below which the rocks are found to be completely saturated with water,—the belt of saturation. The upper surface of this belt of saturation is known as the level of ground water, or the water table. The distance of this level of ground water from the surface varies, depending upon many conditions, such as the amount of rainfall, the kind of rock, the form of the surface of the ground, etc. In general it may be stated that in any given district the level of the ground water is at the surface of the streams in the valleys; from the valleys this level rises under the higher lands on the sides of the streams, and varies somewhat in the same manner as the topography, but it does not become as marked in its variation as does the topography. The water in our ordinary wells is water obtained by sinking these wells to, or a few feet below, the ordinary level of ground water. Of course this level in any one place varies a few feet in different seasons of the year, depending mainly upon the amount of rainfall. In southwestern Wisconsin, especially within the driftless area, the ground water level varies from zero at the sides of the streams to 60 or 70 feet, or even more, on the uplands. At one point southwest of Meekers Grove, in one of the dry-bone mines, the water level was found to be about 100 feet below the surface, and in some places in the district it is even deeper than this.

OPENINGS IN ROCKS.

In its passage through the rocks the water in the earth's crust, both in and above the belt of saturation, flows through openings in the rocks. These openings are of various shapes and sizes, *but the ones* which are of the most importance from the stand-

point of ore deposits may be classed under two heads: first, openings which are due to what might be called porosity of the rock, i. e. to the spaces between the different grains of the rock, and second, openings which are due to fracturing of the rocks. Of course both classes of openings may be, and frequently are, later enlarged by solution. In the first class of openings are included all the inter-pore or inter-grain spaces in ordinary rocks. Many of our standstones contain openings which amount to 10 or 20 or even 25 per cent. of the total bulk of the rock. In some cases the percentage of pore space is even greater than this, as is especially true in some fine grained shales or clays, in which the pore space may run up to 30 or 40 per cent. The pores which are of the most importance in the matter of underground circulation of water are those of the larger sizes, and these occur in the coarser sediments, such as conglomorates and sandstones,—uncemented sandstones being exceedingly favorable media for the passage of water. Uncemented or partially cemented standstones are important factors in the phenomena of artesian wells.

In this connection, however, it is necessary to make a distinction between the actual amount of pore space in a rock, or in other words the amount of water which a given rock will absorb, and the amount of water which can pass through that rock. The first may be regarded as the porosity of the rock, the second as the permeability of the rock. For instance, certain poorly cemented standstones have a high porosity and also a high permeability, i. e. these will absorb and also allow to pass through them large quantities of water, while certain fine grained shales and clays, notwithstanding the fact that they are able to absorb more water than certain sandstones, will allow very little of it to pass through. Thus beds of clay or shale become important stoppers, or directors, of underground solutions, and it is to the confining effect of such beds of impervious rock that the phenomena of artesian wells are partially due. In the lead and zinc district of southwestern Wisconsin certain beds of impervious shale, or clay, have had a very important influence upon

the circulation of underground waters, and consequently upon the formation of ore deposits.

The second class of openings in rocks, i. e. those which are due mainly to fracturing, may be grouped under the head of joint openings, fault openings, openings between bedding planes, and openings due to the slipping of one layer upon another. Of course in these larger openings the circulation of water is more free, and in them, or in the enlarged parts of them, have been deposited the ores of the district.

THE FLOWAGE OF UNDERGROUND WATERS.

As has already been stated, the general direction of flowage of underground waters is from areas of high pressure to those of lower pressure. As an example of this flowage we might mention the waters entering the surface of the ground in an elevated district, such as the broad inter-stream areas in the lead and zinc region. Waters entering in such a position work their way downward by the force of gravity and emerge at a lower level.

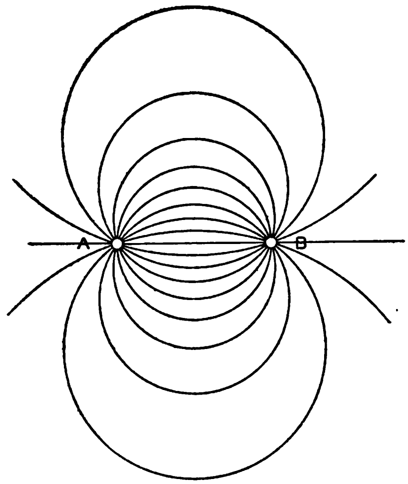

FIG. 1.—Diagram illustrating the horizontal routes taken by water in flowing from one well (B) to another (A). (After Van Hise.)

They, however, instead of passing directly from the point of entrance to the point of emergence, travel by irregular and circuitous routes, and we find that the body of the rock be-

low the surface in the zone of fracture is traversed from top to bottom by these currents of water, although the circulation in the upper part of this zone is in general more rapid than deeper down. A general idea of the complexity of this underground circulation can be gained by consulting the accompanying diagrams (figures 1 and 2), which illustrate the paths by which water will pass from one opening to another, such as between two wells. In figure 2 water passing from B to A pursues the routes shown by the curved lines. Of course the main amount

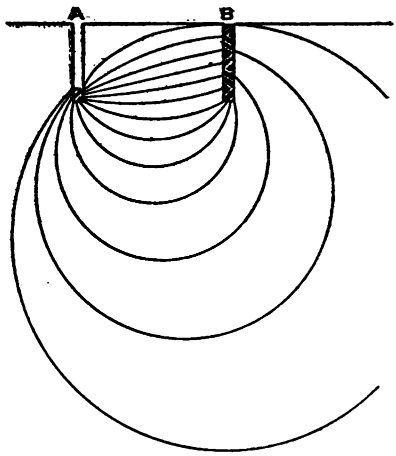

FIG. 2.—Diagram illustrating the vertical routes taken by water in flowing from one well (B) to another (A). (After Van Hise.)

of water passes along the more direct courses, while a smaller, and at times insignificant amount, passes by the more circuitous routes. In this figure is shown diagrammatically the passage of water from one well to another in a horizontal direction, while in figure 2 the same thing is shown in a vertical direction. A diagrammatic illustration of this circulation of underground waters from highland to lowland is shown in figure 3. A comparison of these three diagrams will bring out the point already stated that the route of underground water from the place of entrance to the place of emergence is extremely varying and complex, and it will also illustrate the principle that in the zone of

fracture these circulating waters tend to penetrate and to traverse practically all parts of the earth's crust.

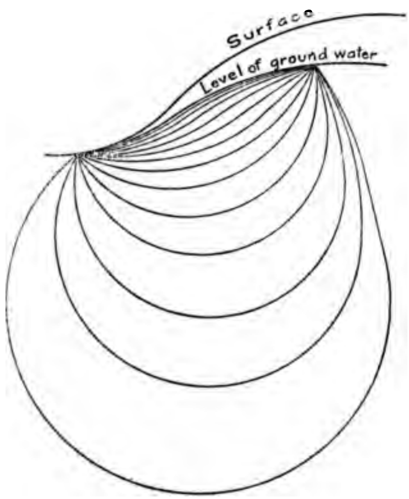

FIG. 3.—Diagram illustrating the routes taken by water which enters the ground at one point on a slope and which emerges at a lower point. (After Van Hise.)

The general course of the downward moving waters and also of those which show a horizontal component is through the smaller openings or pores of the rocks. There is a marked tendency for these solutions to concentrate in, or to flow toward, the larger openings, and it is in these larger openings, especially where the mingling of solutions from different sources occurs, that the main metallic deposits are found. As illustrations of these larger and more extensive openings vertical fault and joint planes can be mentioned. If we assume such a vertical openings with the upper edge in a valley, or in a low district, this opening will serve as a place of emergence for large quantities of water which fall upon the highlands of the district. This water descends gradually through the rocks and is finally concentrated after a long or short journey in this larger opening, and in this opening the general course of circulation will be upward. The idea here explained may be represented diagrammatically by the accompanying sketch (figure 4) which shows

waters descending from the highland, passing through circuitous routes, converging in a larger channel, and emerging again at the surface in the lowland. While this illustration is necessarily diagrammatic and to a certain extent ideal, it nevertheless represents the general principles of underground water circulation. These may be summed up as follows: The water enters the rock, the main part of it in the high areas, and passes downward and horizontally through a series of minute openings. These currents of downward and horizontally moving waters have a tendency to accumulate in the larger openings, and in these larger openings, especially when their tops are in the lowlands, there will necessarily be ascending currents. As will be noted later on, these ascending currents are of great importance in the deposition of ores.

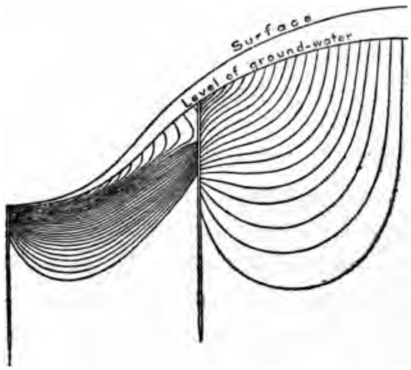

FIG. 4.—Diagram illustrating the waters descending below a slope and converging into vertical openings where they become ascending waters.

It may aid in the general conception of this underground passage of water to compare the circulation in the zone fracture to that which would be established in a U-shaped tube, in which one arm of the U is shorter than the other, and into whose longer arm, corresponding to the highland district, water is poured. The water emerges, after passing downward and horizontally and then upwards through the shorter arm of the U, at a lower horizon than the place of entrance. Of course in nature this U-shaped tube, instead of being simple, is exceedingly com-

plex, the longer and higher arm being made of an infinite number of minute channels, while the shorter and lower arm is composed of one or more channels of much larger size.

While the main cause of the circulation of underground waters is gravity, it should be added that where the circulation goes to a considerable distance below the surface the water becomes warmer, and consequently its viscosity decreases and it will thus circulate more rapidly. However, in the lead and zinc district of Wisconsin there is good reason to believe that the circulating underground waters, to which is due the formation of the ore deposits, never extended to a depth below the surface sufficient to enable the waters to become much warmer than when they entered the ground. So in this district gravity is the all important cause of the underground circulation.

THE WORK OF UNDERGROUND WATERS.

Circulating underground waters form one of the most important geological agents known in the economy of the earth's crust. To these waters are due in large part all those processes known as rock alteration, under which may be included (1) weathering, or the disintegration of rocks at and near the surface of the ground, and (2) those changes which go on below the belt of weathering. In this latter class may be grouped alterations which tend to solidify the rocks, those which tend to metamorphose them and those which tend to carry mineral matter from one point to another. This last is, for our purposes, the most important, but it is only a phase of the vast geological work performed by these underground solutions. The work of underground circulating waters may be grouped under the heads of solution, transportation, and deposition.

Solution. Pure water is capable of dissolving many substances in small amounts, but the water which occurs in the earth's crust is never absolutely pure; in fact it is decidedly impure. Water falling from the sky, as it passes through the atmosphere, takes into solution certain gases, such as oxygen and *carbon dioxide,* and on entering the soil immediately takes into

solution other substances and in its passage through the ground is continually dissolving the mineral matter with which it comes in contact, some substances of course being much more rapidly dissolved than others. Moreover, the fact that the water has become impure, holding in solution certain substances, often enables it to add to its substances still other matter, for water holding active chemical agents will dissolve more substances and in larger amounts than pure water. As an example of this increased power to dissolve substances, may be mentioned the fact that pure water is capable of dissolving only a very small amount of calcium carbonate (the essential material in limestone), while water which contains in solution carbon dioxide gas is able to dissolve a considerably larger quantity of calcium carbonate.

As the waters descend deeper into the earth's crust they become warmer and are under greater pressure. As temperature and pressure increase the dissolving power of the water increases also,[1] and this power becomes very much augmented when the deeper parts of the belt of water circulation are reached. In the Wisconsin lead and zinc district the currents which deposited the ores in all probability never went deep into the earth's crust, and so here the factors of increased temperature and pressure are not of importance.

The substances which are contained in the water circulating in the earth's crust are numerous and complex, and the different substances, which are added to the water in the course of its journey and through whose addition the water becomes able to take up still other substances, are known only in part and need not be discussed in this place, although later a few of the common materials taken into solution will be mentioned. Here it need only be said that these circulating underground waters take from the rocks through which they pass certain substances; and for our purposes the most important of these substances are those which contain lead, zinc and iron. Compounds of these materials are scattered through the rocks in very minute quantities, and it is part of the work of these underground waters to

[1] There are some exceptions to this statement.

dissolve the minute quantities of these substances with which they come in contact.

Underground circulating waters then become, even on their first entering into the earth's crust, weak solutions and these solutions tend to become in general more and more complex and less and less weak as their underground journey continues.

Transportation. The substances which have been dissolved by the circulating waters, which are mainly descending, are transported downward and laterally, passing through large areas of rocks and finally emerging into larger openings, or cavities, where they join the currents of ascending waters. Practically the whole mass of the rocks in the zone of fracture is traversed by these aqueous solutions, which transport from one place to another in the earth's crust large quantities of mineral matter.

Deposition. When these solutions become supersaturated with any particular substance, there is a tendency for the water to precipitate or deposit this substance. The causes important in connection with precipitation, or in other words the causes of supersaturation, are the following: (1) decrease of pressure, (2) decrease of heat, (3) chemical reactions. The chemical reactions, which tend to supersaturate the solutions, are numerous and varied and only the simpler of them are well understood.

The belt of the earth's crust above the level of ground water and for a short distance below this level is the belt in which solutions are mainly taking place. Below this belt, which might be called the belt of weathering, is another belt in which, while solution is taking place, precipitation, and consequently cementation of the rocks, also occurs. It is in the cavities, especially in the larger cavities of this belt of cementation, that there is a concentration of these ore-bearing solutions and the consequent precipitation of the ores and associated minerals.

Returning to the idea of the general underground circulation, it may be stated that where the waters enter the larger openings, and especially where they tend to become ascending currents, there precipitation takes place more markedly than elsewhere. Of course in these ascending solutions the waters are coming under less and less pressure and the temperature is also decreas-

ing; and these two factors will of course lead to precipitation. However, in the lead and zinc district of Wisconsin, as has already been stated, the principal mineral bearing solutions probably never had a marked increase in temperature, nor did they descend deep enough to have the pressure markedly increased. So in this district, at least, these two factors become of small importance. The main factor is the precipitation due to the mingling of certain solutions and to the contact of these solutions with the wall rock. In reference to the first of these cases may be mentioned the fact that very frequently where two fissures cross, the solutions traveling in one of which are a little different in composition from those traveling in the other, we frequently find enriched ore deposits. This is especially the case in some of the mines where a system of cross fissures bring in notable amounts of lead. In other cases the important agents in the deposition of this mineral matter are the rocks which contain organic material. While the Galena limestone does contain small quantities of such matter, the rock which holds it much more than any other is the peculiar narrow bed of shaly material, which occurs at the bottom of the Galena limestone and which has been described under the name of oil rock.[1] It is along this horizon that large quantities of the ores have been deposited, while other large quantities have been deposited just above this horizon. In the first case the deposition was undoubtedly due to reactions between the substances of the oil rock, especially the organic substances, and the ore bearing solutions, while in the second case deposition was due to a mingling of the solutions which carry the ore with solutions carrying material from the oil rock, or to reactions between the solutions and the wall rock.

DEPOSITS MADE BY ASCENDING AND BY DESCENDING SOLUTIONS.

As has already been stated, the ascending waters tend to deposit mineral matter and a large number of the ore deposits of the world are undoubtedly due to waters moving in this direc-

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[1] P 34.

tion. On the other hand it is a well known fact that many ore deposits owe their partial origin, and in some cases probably their whole origin, to descending waters. An example of this origin partially due to descending waters, or what might be called secondary deposition or secondary enrichment of ore bodies, occurs when, due to the processes of erosion, the upper part of an ore bearing fissure has been brought within the zone of weathering. Here the ores, instead of being in the belt of cementation, are now in the belt of solution and are being dissolved and their solutions travel downward; they meet other solutions which may be traveling horizontally, or even upward, and are precipitated by these other solutions, or by contact with the materials of the surrounding rock. In the Wisconsin lead and zinc district it is believed that ore deposits exist, which owe their origin in some cases to ascending solutions (or deep seated circulation), and in other cases to descending solutions, and sometimes to solutions traveling in both directions.

CHAPTER VI.

THE ORE DEPOSITS.

The ores of the lead and zinc district of southwestern Wisconsin consist in: (1) lead sulphide or galena, the "mineral" of the miners; (2) zinc sulphide or sphalerite, the "black jack" of the miners; (3) zinc carbonate or smithsonite, the "dry-bone" of the miners. With the last seems to be more or less hydrozincite, but this is not easily separated from smithsonite, under which name in this report is included all the carbonate of zinc.

The only other original metallic mineral which occurs in considerable quantity intimately associated with the ores is the sulphide of iron; this takes the forms of pyrite and of marcasite, the latter being more common, and all the iron sulphide is here spoken of as marcasite. An oxide of iron (hematite) or the hydrous oxide (limonite) also occurs associated with the galena and smithsonite.

The original minerals of the ore deposits are the three sulphides just mentioned, galena, sphalerite and marcasite. The smithsonite and iron oxides are secondary minerals, having been formed from the alteration of the original sulphides. Small amounts of secondary lead minerals are also found, but not in sufficient quantity to form ores of importance.

The secondary minerals occur in the rocks above the level of ground water or extend a short distance below this level, i. e. they are confined to, and are a product of, the belt of weathering. The original minerals, with the exception of galena which is closely associated with both the original and secondary minerals, occur below the level of ground water.

Intimately associated with the foregoing metallic minerals are considerable quantities of carbonate of lime or calcite, and much less common than this is the sulphate of barium or barite.

The minerals here mentioned are almost the only ones found in the ore deposits of the district.

ROCKS IN WHICH THE ORES OCCUR.

The Galena limestone contains by far the largest amounts of lead and zinc yet discovered in this district. The next important ore-bearing formation is the Trenton limestone. Ore has also been found in the Lower Magnesian limestone and in smaller amounts in the St. Peters sandstone. It has also been reported from the Potsdam sandstone, the Niagara limestone, and also probably occurs in the Hudson River shales. The deposits which are now being worked in the district, and those which have produced by far the largest amounts of the ores in years past, are confined to the Galena limestone and to the upper part of the immediately underlying Trenton limestone.

FORM OF THE DEPOSITS.

The lead and zinc deposits which have been mined in past years occur in a number of different forms. These have been described in detail by Chamberlin[1] and will not be gone into fully in this connection. It is the intention here to describe especially those deposits which lie below the level of ground water, as these are now worked more fully than the others and their importance in the future will be still greater. At the same time there is no intention to intimate that the deposits of lead sulphide and of zinc carbonate which occur above this level are not of importance, for they will continue to be mined as in the past, although on a smaller scale than the others.

The important deposits of lead and zinc ores,—the latter occurring in much the larger amounts,—which are now being worked may be grouped under three classes: (1) Those which occur in certain cracks or crevices in rocks and which are in the

[1] *Geol. of Wis.*, vol. iv, pp. 451–482, 1882.

nature of vein deposits. They are termed crevice deposits and under them are included the flats and pitches of the district. (2) Those which occur in brecciated or very porous parts of the limestone and which may be termed honeycomb deposits. (3) Those which are disseminated in small particles through the rock and do not occur in fissures which were once, or are now, open. These are called disseminated deposits.

Crevice deposits.

The main crevices of the district have a vertical position and run approximately east and west. They are crossed by other fissures, running from north to south, and by certain quartering crevices which cross the others at various angles. The most common of the latter are those known as "ten o'clocks," running about 20° west of north, and those known as "two o'clocks," running about 20° east of north. While the main ores have come thus far from east and west fissures, still noticeable amounts have been and are being obtained from north and south fissures; and it is customary that where two lines of fissures cross the ore deposits are richer, especially in lead.

The vertical crevice deposits usually occur near the upper part or in the upper two-thirds of the Galena limestone. Accompanying them in this part of the Galena limestone are various openings sometimes in the shape of irregular cavities or small caves. As these crevices descend deeper into the Galena limestone they pass into a peculiar form of deposit known as flats and pitches; this form of deposit is characteristic of the district, and it seems certain that a very large amount of the ore which will be mined in the next few years will be derived from these flats and pitches. The form and general character of these peculiar openings is shown in the accompanying diagram (figure 5). The distance between the pitches on either side of a crevice varies greatly but increases as the pitches go downward. In some mines in the lower part of the flats and pitches the distance between the two sides is as much as 100 or 200 feet and in some cases probably more. In other cases mining has not gone far enough to exhibit both sides of the pitches, provided there

are two sides in such cases. As these pitches approach the oil rock they frequently narrow up or run along the top of the oil rock in the shape of flats. At times there is a small deposit of disseminated ore lying in and just above the oil rock between the two sets of pitches. This deposit is sometimes spoken of as the lower flat. It is not universal, however, and at times there is not ore of sufficient quantities in such positions to pay for mining. The writer has been unable to trace any system of flats or pitches directly through the oil rock and the shale and clay which lie beneath it. At the same time it seems probable that in some areas, areas where the disturbance of the rocks reaches its maximum, these fractures do ex-

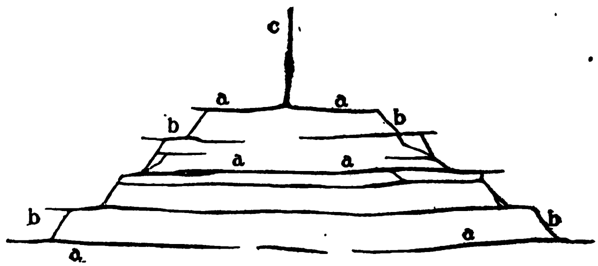

FIG. 5.—Diagram illustrating flats and pitches. *a*, flats; *b*, pitches; *c*, vertical crevice.

tend through the oil rock, shales and clays into the underlying Trenton. In fact, such fractures filled by ore have been reported. At any rate, this upper part of the Trenton, commonly known as the glass rock, is at times traversed by sets of flats and irregular fissures which are filled by ore. One of the most striking instances of this sort occurs about two miles west of Shullsburg at the Little Giant mine, and in this case it is reported that the flats and pitches could be traced unbrokenly through from the Galena into the Trenton.

Another important feature of the flats and pitches, which has heretofore attracted little notice, is the fact that between the two systems of pitches there are frequently several flats running across from one pitch to the other. Of course at many *times only* the upper flat extends from one pitch to the other.

But in some cases, as in the New Deal and Kennedy mines near Hazel Green, a series of these flats is developed between the pitches, thus adding very materially to the amount of ore.

As examples of mines in which the flats and pitches are of particular prominence may be mentioned the Enterprise mine at Platteville, the Trego, Raisbeck and Gritty Six mines near Meekers Grove, and the Kennedy and New Deal mines near Hazel Green.

Order of deposition of the ores. The order of deposition of the original ores in any crevice is as follows: first, on the wall rock comes a coating or layer of varying thickness of marcasite; outside of this is a layer of sphalerite (sometimes containing some galena), and on this sphalerite are galena crystals. This is by far the commonest and may be called the universal order of deposition. While in some cases one of the minerals, especially the galena, may be lacking, at the same time this order is the one which can be seen in practically all the mines of the district where there have been open crevices. Outside of and later than the galena crystals are frequently crystals of calcite, which may fill out the whole cavity; and barite seems to be as a rule still later than the calcite.

This general order of deposition, while almost universal, still has its exceptions or rather its additions, for we frequently find on top of the three minerals, deposited in the regular order as above named, later deposits of either one or two of the others. Not uncommonly a small coating of marcasite is found later than the whole. In some cases on the marcasite there is a thin coating of sphalerite and then a small amount of galena followed by much sphalerite, but in some such cases the galena is mainly, if not entirely contemporaneous with the sphalerite. In other cases where the sphalerite is clearly later than, and not contemporaneous with, the galena, it may be that the later sphalerite is due to secondary enrichment of the vein, as will be mentioned later. At times there has been a brecciation of the ores and a later cementation by calcite, rarely by marcasite.

In any theory which attempts to account for these deposits,

there must be some adequate explanation for this almost universal, simple order of deposition,—marcasite, sphalerite (sometimes with galena), galena.

Honeycomb deposits.

Under this group of deposits are included certain apparently brecciated and very porous parts of the Galena limestone in which the cavities have been more or less filled by the ores. In some cases the brecciation of the limestone is very evident, but in other cases it is quite clear that the limestone was not brecciated but owes its present form mainly to solution. The two cases, i. e. cavities produced by brecciation and cavities produced by solution, pass into each other in the same deposits. It seems quite likely that originally the rock was brecciated or partially brecciated, allowing free access to circulating waters and that these waters have enlarged and added to the cavities by solution of the semi-brecciated or strained limestone. These honeycomb deposits occur sometimes as small openings or enlargements of a crevice, but their main importance lies in the fact that they make extensive deposits, first along vertical fissures, and second along flats. As an example of the vertical deposits of this class may be mentioned the Oldenburg mine near Galena. As examples of these deposits in the form of flats may be mentioned the Strawberry Blonde mine at Strawbridge and parts of the upper flats of the Enterprise mine at Platteville.

The order of deposition of the ore minerals in deposits of this class is the same as in the ordinary crevice deposits, but galena appears to be usually lacking or is present in only small amounts.

Disseminated deposits.

In the lower parts of the mines which show the flats and pitches in their typical development there is found at times in the beds just above the oil rock, also in the oil rock, and at times in small amount in the clay and shale which immediately underlies the oil rock, scattered crystals of ore. This

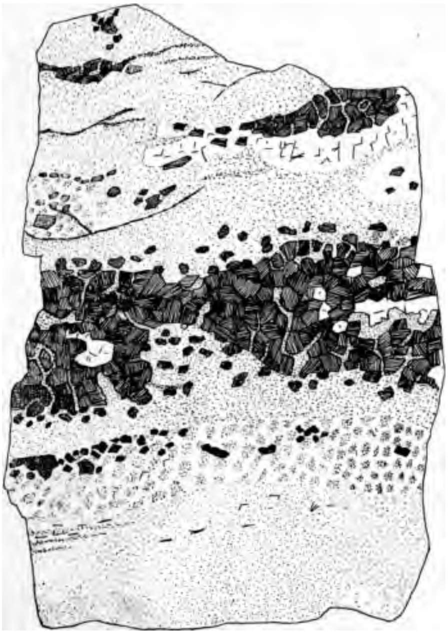

Fig. 1.

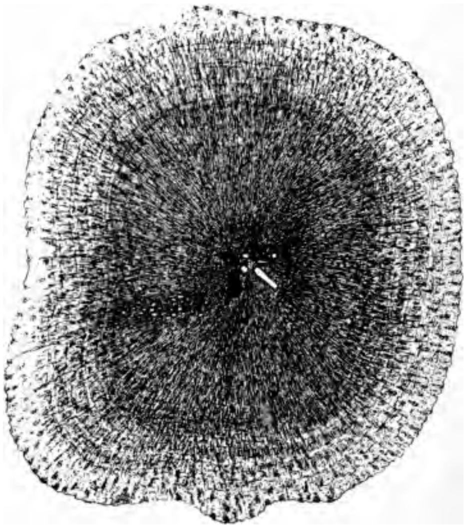

Fig. 2.

Fig. 3.

Fig. 4.

PLATE IV.

FIG. 1.—Disseminated ore in the blue limestone just above the oil rock, St. Rose mine west of Platteville. The stippled areas represent blue limestone, the clear areas calcite, and the dark areas sphalerite.

FIG. 2.—Cross section of a stalactite-like mass, New Deal mine. The solid black in the center represents Galena; the small clear areas represent marcasite; the finely radiating lines show black radiating sphalerite; outside of which is yellow sphalerite in coarse, radiating and concentric structure.

FIG. 3.—Disseminated ore in the oil rock, Klondike mine west of Platteville. The dark areas represent the usual oil rock; the stippled areas porous, lighter colored oil rock; and the dark areas sphalerite.

FIG. 4.-Blue limestone showing barite, sphalerite and galena, Enterprise mine. The stippled areas represent limestone; the clear areas with radiating lines represent barite; the double lined areas sphalerite; the single lined areas, galena.

ore is mainly sphalerite, but galena does occur. In those mines where it is possible to examine the oil rock and the strata immediately above and below it, inside or between the two series of pitches of any range, this disseminated ore has been found in small quantities. Ordinarily, however, it is not in amounts sufficient to be profitably worked. There are, however, certain localities where these disseminated ores, occurring in the strata which have just been mentioned, are of decided importance. As a typical example of such deposit may be mentioned the Graham mine on the east side of the Little Platte river about two miles west of Platteville. In the same general vicinity are several other mines working in the same variety of ore. Among these are the Saint Rose, the Klondike, the Tippecanoe, and the Phillips and Rice. If reference is made to the sections given in the earlier part of this report of the rocks at the junction of the Trenton and Galena limestone,[1] it will be seen that immediately overlying the oil rock is a series of thin beds of blue limestone frequently separated by narrow seams of oil rock. This series of beds is from two to eight feet in thickness and passes into the ordinary Galena limestone above. In this thin series of beds are the main deposits of ore of this disseminated group. (Compare pl. IV, fig. 1.) However, the ore also occurs immediately below these beds in the oil rock (compare pl. IV, fig. 3), and to a less extent in the blue shale or clay which immediately underlies the oil rock. The ore occurs not as a filling to cracks or fissures, although there are at times small cracks which seem to have been filled by the ore, but the crystals of sphalerite have been developed within these blue beds of limestone and within the beds of oil rock. In other words, there has been a substitution of sphalerite for part of the substance of the limestone and with this sphalerite is at times more or less calcite.

All such deposits that have been seen occur along the sides of valleys which have been cut down into the Trenton limestone or even lower. In other words, the oil rock and the shales that separate the Trenton from the Galena are in all these cases

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[1] Pp. 28-36.

above the present drainage level of the vicinity. Moreover, as far as seen these deposits occur near the bottom of small valleys tributary to the main river valleys. Of course the occurrence of ore in such positions would be the first to be recognized in prospecting, and it may be that this ore will be found not only under these valleys, but also under the higher land which separates them. At the present time, however, mining has gone only far enough to show that along these small valleys the ore does occur. At present it is not possible to say how these deposits of ore trend, that is, it is not possible to state in what direction the longer axes of the ore bodies lie. It is found that along these deposits there are several small cracks or fissures, cracks, however, which have not been opened wide and in which no particular amount of crustification has taken place. Cross cracks also come in, and sometimes along the crossing of two series of cracks, especially at the Graham mine it is found that lead occurs more abundantly than elsewhere. The lead occurs in the same manner as does the sphalerite. Judging from the descriptions which have been given heretofore of the flats and pitches, especially what have been called the lower flats or the flats that lie immediately along the upper edge of the oil rock, we would expect to find in such situations higher up in the strata the ordinary flats and pitches of other localities. At the present time, however, such have not been discovered in mines in which these disseminated sulphides are the principal ores.

One important feature of these disseminated ore deposits is that they contain, at least so far as developed, a much smaller amount of iron sulphide than do the ordinary deposits of the district. At the same time it should be stated that so far as yet worked, these deposits are close to, if not within, the belt of oxidation. In fact, in some instances the remains of oxidized iron sulphide have been found, and it seems reasonable to expect that as these deposits are followed into the hills below the level of the ground water marcasite will increase in abund[illegible]theless, even in the freshest of the rock exp[illegible]ich seems to show no evidence of oxida-

tion, there is a comparatively small amount of iron sulphide. In this respect these ores are especially important. Moreover, the rock in which they occur, especially the oil rock, and even the blue limestone, is in general considerably softer than the main Galena limestone and so is easier to mine and crush.

Already two concentration mills have been built at mines of this character and it seems very probable that these disseminated ore deposits, which of course have been known before but which have never been worked in large amount, will become an important factor in the production of the higher grade ores from this district.

DESCRIPTION OF MINES.

Below will be found notes relating to some of the mines of the district. It was impossible during the time allotted for the preparation of this report to visit all the mines, and likewise impossible to study carefully many of those that were visited. No attempt is made to describe any one mine fully. The mines here selected are those which show certain interesting or typical features regarding the ore deposits.

Enterprise mine at Platteville.

The shaft goes down on an east and west crevice, which is said to have been worked for lead ores some years ago, and is about 145 feet deep. About 40 feet down the shaft is an old opening which has been worked somewhat; it runs approximately east and west. Here there is smithsonite, some blende which is altering to smithsonite, a little galena and considerable marcasite. The last occurs especially in radiating masses. Lower down the shaft, about 50 to 80 feet from the surface, are openings which show large quantities of marcasite and a little galena and sphalerite. From 90 to 100 feet are other openings in which marcasite is abundant, lining the cavities. The main mining is done from about 100 feet down to 130 feet below the surface. Here there is a large amount of blende and also toward the western end of the mine considerable lead.

The usual order of deposition is (1) marcasite, (2) sphalerite, (3) galena. Very frequently, especially toward the west end of the mine, there is considerable galena mixed with the sphalerite, and while they seem to be at times contemporaneous, at other times the order is: marcasite, blende, blende and galena, blende.

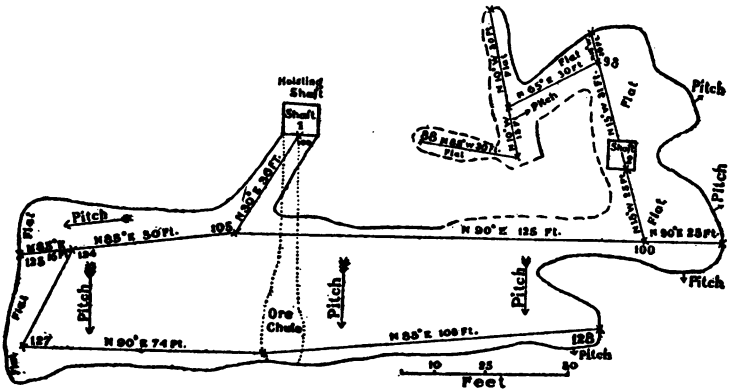

FIG. 6.—Map of the Enterprise mine. Rock walls of workings shown by full lines; filled walls of working by broken lines. Figures near crosses indicate approximate distances, in feet, from surface of the ground at top of hoisting shaft.

The mine is along a series of flats and pitches which strike nearly east and west. These are crossed by a second and less important series which runs a little west of north. In the accompanying map of the mine (figure 6), the relations of these two series of flats and pitches are brought out. The east pitches of the north and south group are well shown toward the eastern part of the mine and also come out in the main workings in the western end of the mine. The south pitches of the east and west system are beautifully shown for practically the whole length of the mine, and it is from these south flats and pitches that the main ore has been taken. Explorations have not gone far enough to prove whether or not there is a north series of flats and pitches belonging to this east and west system.

At the exteme north point of the workings, which is about 90 feet from the surface, there is a sheet of ore, and below it is some of the honeycomb rock with cavities lined by marcasite. Just to the east of this and dipping in a direction a little north

of east is a small pitch which goes down from this flat six or eight feet to a lower flat, which is the main flat of the eastern end of the mine. At the extreme eastern end of this flat the pitch goes off again a little north of east. Along this large flat is considerable ore, and below the main flat is a smaller flat one or two feet distant. Below both of these flats and sometimes between them is some of the honeycomb rock, lining the cavities of which is marcasite and sometimes a little blende. The eastern flat has some galena and only a small amount of calcite.

The main workings of the mine are along the chief pitch which dips to the south about 30°. This pitch is not always continuous but is interrupted for a short distance by small flats, some of which run back towards the center of the mine. At the extreme west end of the mine, where work is now going on, there is a large flat, or rather, two or three and sometimes more flats within a distance of five or six feet vertically. At this point a considerable stream of water issues from an opening of the main flat. This water is clear and cool and there are no oxidizing effects shown along the openings at this place. However, in places where the water has trickled down for several weeks there is a small deposit of iron oxide, showing that the water carries at least iron in solution, which is precipitated on coming in contact with the oxygen in the mine.

In the lowest part of the mine the oil rock is exposed and in places in this, and in the blue limestone just above, is barite which encloses crystals of blende and also of galena.[1] (See pl. IV, fig. 4.)

New Deal and Kennedy mines near Hazel Green.

These mines are along a north and south range, but in the New Deal, which adjoins the Kennedy on the north, the range is bearing more toward the west. Flats and pitches are beautifully developed in both mines. The upper flats are 100 to

[1] For a section of the strata in the vicinity of the oil rock at the Enterprise mine see p. 31.

150 feet wide and the pitches go down on both sides of these. Several lower flats are seen and at least in some cases these appear to run back the whole width between the pitches. These cross flats, i. e., those which run from pitch to pitch below the upper flat, are proving an important feature in the mining of the district, and in these two mines are developed to an extensive degree.

The first flat in the Kennedy mine is some 60 feet above the oil rock and is near the water level. It contains a little smithsonite, and much clay and limonite; marcasite is also very common. Below the water level the flats and pitches are seen in more perfection, and here the order of deposition is: marcasite, blende, galena. Thick masses of marcasite are seen along the bottom of some of the flats. Along the pitches are at times large cubes of galena, and this galena seems to be more abundant near the upper flat, where it is altering to lead carbonate. There are some stalactite-like masses in these flats, and in the upper flats the marcasite of these masses has commonly altered to limonite. One such mass which was fresh showed the following from within outward: first a cavity of about one-half inch in diameter, then a layer of marcasite one-half inch thick; then a layer of blende one-quarter inch thick, and outside of this was a layer of marcasite one inch in thickness. Considerable of the marcasite in this mine is later than the blende, although the main part of this iron sulphide seems to have been the first mineral deposited. In a number of cases it is found that the order of crustification has changed several times from marcasite to blende.[1]

At the New Deal mine in the oil rock are seen a few lens-shaped masses of limestone which closely resemble glass rock. These lenses are from one to six inches thick and from six inches to several feet in length. There are also some larger masses which are probably of the same nature which are a foot or two in thickness and from two to six feet in length. The oil rock

[1] For a section of the strata in the vicinity of the oil rock at the Kennedy mine see p. 31.

surrounds this glass rock and also penetrates it in thin layers. The usual order of deposition in this mine is: marcasite, blende, galena, calcite. It is estimated that at least three-fourths of the marcasite seen here is earlier than the blende. A common feature of this mine is the round stalactite-shaped masses which are made up largely of blende. One of these is represented in the accompanying figure (plate IV, figure 2). The common order in these stalactite-like masses is: in the center marcasite, yellow blende, dark almost black blende in a thick layer, then a thin layer of yellow blende. Occasionally just outside of the thick layer of black blende is a thin layer of marcasite. The radiating nature of both the blende and the macasite is very finely shown in most of these specimens. Not infrequently the core of these stalactites is of galena. In some cases these stalactite-like masses have the outer surface made of blende, and in other cases the outer surface of marcasite, and it is not uncommon to find both of these side by side. The main part of the stalactite-like masses is of blende with only a subordinate amount of marcasite.

Trego, Raisbeck and Gritty Six mines near Meekers Grove.

These three mines are probably on the same line of crevice which runs approximately east and west, and the workings are along flats and pitches. At the Trego mine the common order of deposition is (1) marcasite, (2) blende. At the Raisbeck there is a noticeable amount of barite, and in cases this is clearly seen to be later than the galena.

At the Gritty Six mine the usual order of deposition is marcasite, blende, and then calcite; in fact, at some points in this mine there are very fine masses and crystals of calcite. Another order is: marcasite, blende, cavity, and then much marcasite on the lower side of the cavity, especially in radiating, concentric arrangement. At times the order is: marcasite, blende, cubes of galena. Calcite occurs at times on the galena; and near the oil rock is some barite, which in some places is seen to be later than the calcite. The usual order then is: (1) marcasite, (2) blende, (3) galena, (4) calcite, (5) barite. In

some cases a later coating of marcasite is seen on the galena, but whether this coating is ever earlier than the calcite and barite is not evident. The mine is about 90 feet deep and goes down to the oil rock. In the oil rock are a few scattered cubes of galena. Also small flats are seen in the upper part of this oil rock. A short distance southwest of the main shaft the rock is much broken and it seems as if the flats were pitching down through the oil rock, but this point was not determined definitely. The rocks at this mine dip irregularly, but in general there is a dip of 5° to 10° toward the north-northeast.[1]

Little Giant mine near Shullsburg.

This is situated at the extensive open pit excavation which was made some years ago by the Wisconsin Lead and Zinc company. From the north side of this excavation the present Little Giant mine has a tunnel running into the hill for about 250 feet. Here ore occurs in flats and pitches, the pitches dipping toward the north. There is marcasite and a little barite in this tunnel.

Near the south side of the old open workings the Little Giant mine has sunk a shaft through the oil rock. This is about 30 feet in depth and shows the following section:

6. Yellow decayed limestone	1 foot.
5. Soft sandy material, oil rock and soft yellow sandy clay confused, with the oil rock mainly in the lower half	3 ft., 6 in.
4. Blue shale	2 feet.
3. Blue shale with thin layers of oil rock	1 foot.
2. Very hard, compact, fine-grained limestone resembling, but coarser than, the typical glass rock	6 feet.
1. Same as the last but holding small flats and fractures which are filled with ore	7 feet.

Below this the shaft is said to have been sunk 22 feet further through the same kind of rock, and in this rock is said to have existed similar flats and crevices filled with ore. At the present time these lower workings are hidden from view on

[1] For a section of the strata in the vicinity of the oil rock at the Gritty Six mine see p. 31.

account of water, as they are below the level of the creek at this point. The general order of deposition of the ore at this point is marcasite and then blende. The rock at this place which lies below the oil rock is a hard, brittle, fine-grained limestone, and it has been fractured through and through, the fractures being filled by deposition of metallic sulphides. It is reported that a short distance from this place the pitches had been traced actually down through the oil rock and the clay which lies below it and into this brittle, hard limestone, which corresponds in general to the glass rock farther west.

Oldenburg mine near Galena.

This mine is along an east and west crevice, or rather along two nearly parallel crevices which unite toward the eastern part of the mine. The ore body is in a vertical sheet and is an example of the honeycomb deposits. The thickness of the sheet varies from almost nothing up to about 30 feet, and has been mined for about 800 feet in an east and west direction. A small amount of lead is present. Where small north and south crevices cross the main crevice, are usually larger and richer deposits of ore. The customary order of deposition in the cavities in this honeycomb deposit is a thin coating of marcasite followed by blende. Mr. Richard Kennedy informs me that the bottom of the mine, which is now about 100 feet under the top of the hill, is still 100 to 125 feet above the oil rock horizon. Further work here will quite probably develop a series of flats and pitches above the oil rock.

The Strawberry Blonde mine at Strawbridge.

The ore here occurs in a flat which is from one to five feet in thickness and is a typical example of the honeycomb ore. The usual order of deposition in the cavities of this rock is: marcasite, blende, calcite. A small amount of lead was noted. The ore body, which is now exposed in drifts, is 60 to 70 feet wide, and it appears to run east and west. The connection of this ore body with other flats, or with crevices or pitches, is not evident.

Graham mine near Platteville.

This mine is a typical one of the class of disseminated deposits. Here a section through the oil rock is as follows:

4. Thin beds of blue limestone separated by narrow bands of oil rock. Frequently this blue limestone is turning brown from oxidation along the cracks at the edges of the bands. This is the chief ore horizon, blende and galena being both found in this blue limestone and in the accompanying narrow bands of oil rock	4 feet.
3. Oil rock mixed with sandy shales and some thin bands of pure limestone which carries ore in the same manner as No. 4	8 inches.
2. The main oil rock, also containing ore................	1 ft. 6 in.
1. Blue shale, also containing ore	1 ft. 6 in.

While the work has not developed far enough to show the form and the size of the ore deposit, it still appears that the main ore is running in a general east and west direction, or, more strictly, probably a little north of west. The ore is mainly the disseminated sphalerite but there is some galena, and this is especially the case near the crossing of two crevices in the mine, at which location galena is very abundant and seems to replace the sphalerite, at least in part. The thin band of blue limestone, No. 4 of the above section, is the main ore horizon. Along the cracks and bedding planes of this limestone there has frequently been considerable oxidation. By this oxidation some of the marcasite may have been altered so that its presence is not easily recognized. At the same time there is considerable of this rock which seems to be fresh and unoxidized and in this marcasite is very rare, although there are occasionally small amounts of it. The practical absence of marcasite from these disseminated deposits has already been commented upon.

SECONDARY ORES.

As has already been stated, the chief secondary ore of the distric is smithsonite or dry-bone. This is found in the belt

of oxidation or mainly above the level of gound water, although this material occurs also a few feet below this level. It is a well demonstrated fact that these deposits of dry-bone are formed by the alteration of sphalerite (ZnS) to zinc carbonate or smithsonite ($ZnCO_3$). One reaction by which this takes place is probably as follows:

ZnS (spharelite) + $4O$ (oxygen) = $ZnSO_4$ (zinc sulphate).

The zinc sulphate is soluble, but it is precipitated in part by the calcium carbonate held in solution in the water or else existing in the adjoining rocks according to the following reaction:

$ZnSO_4$ (zinc sulphate) + $CaCO_3$ (calcite) + $2H_2O$ (water) = $ZnCO_3$ (smithsonite) + $CaSO_4.2H_2O$ (gypsum).

Gypsum is soluble in water and is carried away or is in this region rarely deposited in the immediate vicinity.

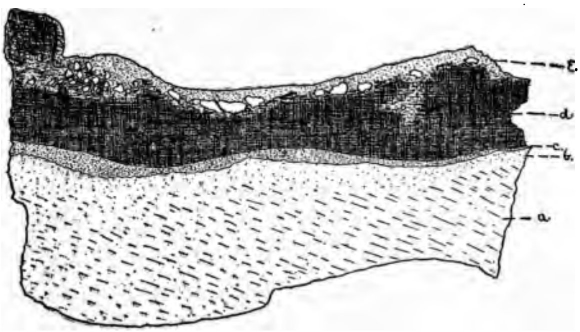

FIG. 7. Specimen showing the usual order of deposition of the ores and their alteration. *a*, compact, fresh limestone passing into altered, partly porous limestone, *b*; *c*, thin layer of marcasite altered in part to limonite; *d*, fresh sphalerite; *e*, smithsonite formed from the sphalerite.

Many specimens can be found (compare figure 7) where the unaltered interior of a piece of ore is clean, fresh sphalerite, but this gradually passes into smithsonite on the exterior. The smithsonite, while occupying as a rule the same space as the original sphalerite, still contains a much smaller percentage of zinc and moreover is extremely porous in its structure. It is thus quite clear that all of the zinc of the original sphalerite is not precipitated by the reaction given above, but part of it passes into solution and seeps downward in the earth's crust.

The importance of this zinc which is thus migrating downward will be spoken of later in reference to the enrichment of the ore deposits.

Along with this alteration of the sphalerite goes on the oxidation of the marcasite. Some of this iron oxide remains in the place of the original marcasite, and in cases part of it also joins the circulating waters. In fact, marcasite is as a rule attacked much more readily by oxidizing waters than is the sphalerite, so we frequently find associated with deposits of smithsonite more or less iron oxide usually in the form of limonite.

The lead sulphide, galena, on the other hand is much less subject to alteration than are the sulphides of zinc and of iron. At the same time galena is altered and its alteration products dissolved and carried downward. Nevertheless, due to the fact of its imperfect solubility and also to the fact that it is when taken downward in solution precipitated before the other metallic sulphides, the upper parts of many of the crevices contain considerable quantities of lead ore. This lead ore is oxidized and altered not more rapidly than the general weathering of the surrounding rock, and it thus frequently is found practically at the surface of the ground. While sphalerite and even the smithsonite alter and are taken into solution more rapidly than the weathering of the surrounding rock and thus very rarely are these zinc ores found at the surface of the ground, the exception being in those positions where erosion is more active than weathering.

The statement that lead ore is more abundant at higher levels than the zinc has hertofore held true probably for the reasons given above, i. e. it is there because it is less soluble than the other metallic sulphides and also because when taken into solution it is the first to be precipitated. It is possible also that in the original deposition of the ores the galena was deposited more abundantly in the upper part of the crevices. At the same time, attention should be called to the fact that recent mining has in a number of places discovered notable quantities of galena at a considerable distance below the level of

ground water. But in this case the lead ore is mostly mixed with the sphalerite, i. e. was probably deposited contemporaneously with the sphalerite, and does not occur in the large crystals which are so common in the higher portions of the veins.

ORIGIN OF THE ORES.

Under this head an attempt will be made to explain briefly the origin of these ore deposits, or, in other words, to present a theory which will account for their present condition. In this, attention will be called to the fact that the ore deposits are due very probably to a combination of two origins, one, that of a deep-seated or artesian circulation such as has been described by Van Hise, and the other to a shallow, downward circulation of the waters such as has been described by Chamberlin and has also been made use of by Van Hise in his explanation of the secondary enrichment of these ore deposits. It is not always possible to separate entirely ores which were deposited in one manner from those which were deposited in the other. At the same time, it might be stated that there seems to the writer to be good reason for believing that the first ores of the district were deposited by deep-seated circulating waters. To this kind of deposition are referred the bodies of ore which show so clearly the regular order of deposition which has been mentioned before, i. e., marcasite followed by sphalerite. Of course it is impossible at times to say whether a considerable quantity of this sphalerite has not been deposited later by descending solutions. In fact, there seems to be considerable evidence pointing to the fact that in some of the deeper mines this original sphalerite is still being added to by waters of the present circulation. And these waters of the present circulation may be included under two classes: first, those which come directly from the surface along the fissures, and, second, those which have come from considerable distances and now enter the main channels of circulation. The first class of waters are descending and are regarded as the means of the secondary enrichment of the ore deposits, while the second class of waters,

even though they are not necessarily ascending in all cases at the present time, belong to the deep-seated circulation and are to some extent the means of the original first concentration of the ores.

On the other hand, there are certain deposits, namely, those which are here described as the disseminated ores, which seem to owe their origin in large part to descending waters, i. e. to waters which have descended through the Galena limestone to the oil rock and shales below and have been turned in their courses by these less pervious strata.

Attention should, however, be called to the fact that the ore deposits of this district have not been subjected to detailed investigation since mining has extended much below water level, and there are many factors regarding the origin and relation of these ores which can not be fully understood before the region has been examined in a very detailed and very critical manner. Thus many of the statements here made concerning the origin of the ore deposits are necessarily of a preliminary and tentative nature.

Traced to their ultimate origin we find that the metallic sulphides find their home in the igneous rocks. These substances have been taken from these rocks by solution and by mechanical disintegration and have been transported and deposited among the sedimentary rocks. This process may have gone on a number of times, and any lead and zinc sulphide which we find in sedimentary rocks today may have existed in several other series of sedimentary rocks. These metallic sulphides are found to be dissolved in minute quantities in sea water, and they also occur in many of the vegetable remains which accumulate and grow in sea water. The accumulation and decay of such vegetable remains in the rocks is certainly one means of deposition of these sulphides.

It is sufficient for our purpose to state that at the time of the deposition of the Galena limestone, lead and zinc, in minute but widely scattered particles, accumulated in that formation. We are unable to certainly trace the lead and zinc of the Wisconsin ores to a more remote source. Just why this limestone

should be selected as the home of these metals is a difficult question to answer and one on which the writer is not able to venture an opinion. At the same time, it seems to be an undisputed fact that the magnesian limestones of the Mississippi valley are the homes of the lead and zinc. Chamberlin in his report on the ores of this district proposed and explained a theory of oceanic currents and consequent deposition which would account for the accumulation of the lead and zinc in such quantities in the Galena limestone of the upper Mississippi valley.[1] It must not be thought, however, that in any part of the Galena limestone these ores were at first deposited in such quantities as to be noticeable. The truth is that they were so extremely finely disseminated that they could not be detected by odinary means. As an example of the extremely minute quantity of these ores which it is necessary to have in any given thickness of the Galena limestone, in order to furnish a basis for the present ore deposits, the following statement may be quoted:

At my suggestion, Mr. I. M. Buell made an estimate of the amount of impregnation of the rock that would occur, if the entire quantity of ore taken from the Potosi district were uniformly distributed through the adjacent rock. This district was selected because (1) it has been one of the most productive, (2) has definite outlines, (3) a somewhat uniform distribution of crevices, and (4) is withal one of the most concentrated districts of the whole region. In determining the limits of the district, a margin outside the outermost crevices was allowed equal to half the average distance between the crevices, i. e., the outside crevice was supposed to draw only as much from the territory outside as from that between it and its neighbor crevice. As the basin occupied by the district extends some distance on every side, this is a very moderate assumption. Furthermore, it was assumed that only 100 feet in depth had been leached in the derivation of the ores, although probably twice that amount of rock originally lay above the base of the deposit. The result was *one fourteen hundredth of one per cent.*, or a little more than seven-millionths part of the rock, a quantity that may seem surprisingly small to those who, by dwelling on the relative value of the ores, magnify their relative quantity, a

[1] Geol. of Wis., vol. iv, pp. 482–488, 1882.

quantity certainly small enough to answer certain inconsiderate objections to the theory of derivation of the ores from the enclosing rock, based on the want of ocular evidence of their metalliferous character.[1]

As has already been explained, part of the important work of underground waters is to dissolve, to transport, and to collect in favorable positions these scattered minerals, particularly the ores. This has been done for the lead and zinc district in general in the same manner as other ore deposits have accumulated in other districts. However, there are in southwestern Wisconsin certain peculiar features to which attention should be called. Important among these is the fact that the strata dip toward the southwest at a considerable angle, an angle which is ordinarily greater than the slope of the country. The Galena limestone itself is a rock which contains cracks and fissures of various kinds, in other words it was a rock which factured readily when subjected to the slight deformation which this region has undergone. Lying above the Galena limestone is a considerable thickness of soft shales, while just below it, separating it from the Trenton, is a much less thickness of soft shales and clays. The Galena limestone is thus enclosed between two rather impervious beds, and not only beds which are impervious but beds which do not respond to slight deformation by fracture. Moreover, aside from the cracks and fissures which exist in it the Galena limestone is a comparatively porous rock,—much more porous than many of our limestones, especially more so than much of the Trenton. We thus have a porous bed limited above and below by impervious beds, the whole dipping in a proper manner, and outcropping at the north at considerably higher levels. This, of course, was the condition of the district before erosion had removed the Hudson River shales. There were thus ideal conditions for artesian circulation, conditions similar to those of the artesian circulation which now takes place in the St. Peters sandstone and to a larger extent in the Potsdam sandstone.

The artesian waters flowing through the Galena limestone would reach the surface either through some important fissures,

[1] *T. C. Chamberlin*: Geol. of Wis., vol. 4, p. 538, 1882.

fissures which were strong enough to penetrate the overlying beds of shale, or else, as was more probably and more commonly the case, would come to the surface where these beds of shale had first been cut through by erosion. The accompanying diagram (figure 8) will aid in the understanding of this general law of artesian circulation in the Galena limestone.

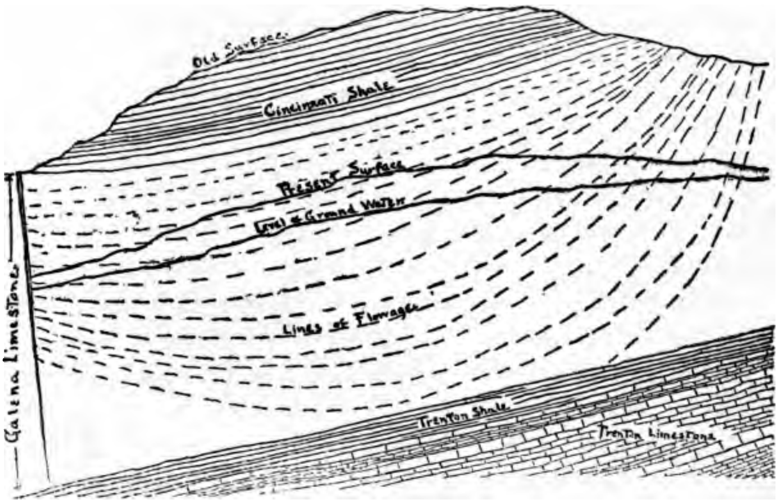

FIG. 8.—Generalized section, from northeast (right) to southwest (left) of the lead and zinc district. After Van Hise.

It is very evident that if such a circulation as this did exist there is here an adequate means by which the strata of the Galena limestone could be searched from top to bottom for a long period of time by artesian waters, waters which on account of the considerable pressure that they were under would flow more copiously than is oftentimes the case in the underground circulation. The chief value of this artesian circulation, at least as it appears to the writer, is the furnishing of such an adequate means for the thorough search by the waters of the whole thickness of the Galena limestone, and the furnishing also of a common method of ore deposition, i. e. by ascending waters in crevices. Moreover, as was stated in the discussions of the ore deposits themselves, there is in these ore deposits an almost uni-

versal order of deposition, an order which is varied only in a few cases, but it may have added to it other orders of deposition; still the common order remains practically constant for the whole district. It seems very reasonable to suppose that this peculiar order of deposition occured under conditions which were uniform for the whole district, and that this order of deposition should have been changed and other orders added to it only when the conditions changed; but this change of conditions was brought about by the inauguration of a different method of water circulation, i. e. the one which is so prominent now,—a descending circulation.

At the same time, while the artesian circulation furnished a very adequate means for the thorough search by the waters of the Galena limestone and the consequent first concentration of the ores, it is quite probable (as noted on page 80) that a less rapid and yet an important deep-seated circulation went on long after true artesian conditions ceased and is even going on today. In other words the deep-seated waters, which are in some cases even today probably actually ascending waters, were and are agents in the first concentration of the ores. If this conception is correct, the period of the first concentration is very long and as yet we have no means of separating the deposits made by the artesian circulation from the first concentration deposits made later.

Assuming that the artesian circulation, which has been noted above, took place, we find that many of the crevices are being traversed by ascending currents of water which carry dissolved in them considerable quantities of the metallic salts, which have been derived by these same waters in their passage through the Galena limestone. The precipitation of the ores in the crevices from these ascending solutions may have taken place, and probably did take place, in a number of different ways. That some part of the precipitation was due to a mingling of solutions of different composition coming from different sources is evidenced by the fact that where certain fissures cross there we find specially large amounts of ore deposited. Attention has already been called several times to the fact that the ore

deposits are frequently richer in galena at the crossing of one fissure with another, and the miners of the district especially desire to find crossings of several sets of fissures in their mines, knowing that as a rule it is along these crossings that rich ore deposits are to be found.

Another and a very important cause of precipitation of these ores was the organic material contained in the Galena limestone and especially in the oil rock at the base of this limestone. If the ore held in solution is in the nature of a sulphate, it can be precipitated as a sulphide (the form in which the ore now occurs) by the simple abstraction of oxygen by carbonaceous material derived from organic substances. This precipitation by carbonaceous matter probably accounts for the large accumulation of the ore at and near the bottom of the Galena limestone, i. e. in the vicinity of the oil rock which is even today a highly carbonaceous stratum.

Another means of precipitation is by the action of hydrogen sulphide, which material is found to be a rather constant constituent of the deep seated waters in this region. The reaction which takes place in this manner of precipitation of sphalerite may be expressed as follows:

$$ZnSO_4 \text{ (zinc sulphate)} + H_2S \text{ (hydrogen sulphide)} = ZnS \text{ (sphalerite)} + H_2SO_4 \text{ (sulphuric acid)};$$

and for galena this same reaction would be expressed

$$PbSO_4 \text{ (lead sulphate)} + H_2S \text{ (hydrogen sulphide)} = PbS \text{ (galena)} + H_2SO_4 \text{ (sulphuric acid)};$$

These two means of precipitation, i. e. by carbonaceous material contained in the rocks themselves and by hydrogen sulphide contained in the water, will probably account for a considerable amount of the ore. There is no intention, however, of stating that other and more complex reactions may not have taken place and probably did take place. The nature of these, however, is not fully understood.

When erosion progressed far enough to bring the upper part of a crevice in which these metallic sulphides had been deposited within the belt of oxidation or the belt of weathering, a totally different series of reactions took place. As has already

been explained in the formation of the smithsonite,[1] a considerable part of the zinc went into solution and was carried away. The same is true of the iron and to a less extent of the lead also. It is practically certain that parts of the solutions derived from this oxidation of the lead, zinc and iron sulphides in the belt of oxidation would find their way downward along the crevices. Moreover, it is also probable that waters coming in from the sides and traversing more or less extensive areas of Galena limestone, thus taking into solution these metallic salts, would also find their way along these crevices. As these waters passed below the belt of oxidation, i. e., as they reached water level or a short distance below water level, there very probably was a tendency to precipitation in the order of their affinity for sulphur, lead having the much greater affinity for sulphur than zinc and zinc much greater than iron. In such cases the reaction which might occur in descending solutions of zinc sulphate has already been given.[2] The same would take place for lead sulphate.

But the zinc sulphide and the iron sulphide may also act as means of precipitating the lead sulphide, according to the following reaction:

$PbSO_4$ (lead sulphate) + FeS_2 (marcasite) + $_2O$ (oxygen) = PbS (galena) + $FeSO_4$ (iron sulphate) + SO_2 (sulphur dioxide).

And the same reaction in case of the carbonate, is

$$PbCO_3 \text{ (lead carbonate) } + FeS_2 + 2O = PbS + FeCO_3 \text{ (iron carbonate) } + SO_2.$$

The greater affinity of lead for sulphur will probably thus explain the precipitation of the lead sulphide first, i. e., at higher levels.

The zinc sulphide may act in a somewhat similar manner to the iron sulphide in precipitating galena, according to the following:

$$PbSO_4 + ZnS = PbS + ZnSO_4,$$

Also

$$PbCO_3 + ZnS = PbS + ZnCO_3.$$

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[1] See p. 75.

[2] See p. 83.

In this last case smithsonite would be precipitated, and of course it is a well known fact, to which attention has already been called, that smithsonite and galena are intimately associated in the upper parts of the ore deposits.

In passing farther down the next substance to be abstracted would be zinc according to the following reaction:

$$ZnSO_4 + FeS_2 + 2O = ZnS + FeSO_4 + SO_2,$$

and also

$$ZnCO_3 + FeS_2 + 2O = ZnS + FeCO_3 + SO_2.$$

In this manner the sulphides of iron (pyrite and marcasite) would be the last to be precipitated and would be found at lower levels. This will probably account for the fact that in some of the mines we find a coating of marcasite which is later than the other sulphides. In such cases the other sulphides might be regarded as dating from the original ascending circulation and the marcasite considered as a secondary deposit by descending waters.

Thus the general rule for the occurrence of these ores would be in the higher levels galena, then galena associated with smithsonite, then sphalerite, and still lower down the original lean sulphides consisting of considerable amounts of marcasite and smaller amounts of sphalerite and galena. Thus in many mines it is found that the ores grow poorer with considerable depth. At the same time whether the lower levels of the mines in the lead and zinc district of Wisconsin are richer in marcasite is an open question. The writer has not yet been able to demonstrate that this is always the case, although there is no doubt but that it is sometimes the case. On the other hand there are certain of the deeper mines, especially the Enterprise mine at Platteville, which show a considerable amount of marcasite at certain levels considerably below the level of ground water, but which in the lower parts of the mine show richer masses of sphalerite with only a small quantity of the original marcasite. Just what this means and just what the cause of this is, is uncertain. Moreover, this fact has not been found in a sufficient number of cases to enable one to draw definite conclusions from it. But it does seem very probable from the facts at hand that in the deeper

mines, that is, those which go down a considerable thickness,—say 125 to 250 feet into the Galena limestone,—there may be found in the lower levels ores which are not contaminated by large amounts of the iron sulphide. It is with considerable interest that we can thus look forward to the exploitation of some of the crevices which begin well up toward the summit of, or at least considerably above the upper half of, the Galena limestone.

While the crevice deposits, made by ascending waters and added to by descending waters, were very likely formed in the manner already explained, this same explanation will not hold for the disseminated ore deposits. In this latter it seems very probable that descending waters have played a leading part. Of course, as already stated, mining has not gone far enough to demonstrate whether above these disseminated deposits there exist series of flats and pitches. This may be the case, but if it is the case in every mine, it seems peculiar that some evidence of these flats and pitches should not have been found before now. Of course reference is made here only to those deposits which are clearly disseminated, as for instance those which occur along the Little Platte river west of Platteville, and reference is not here made to small quantities of disseminated ore which are sometimes found at or near the oil rock below the flats and pitches.

All of these disseminated deposits thus far studied are situated today above the drainage level of the district. They also are very probably situated along a series of crevices, and whether they are in small synclines cannot be stated, although it seems likely that they are thus situated. It appears that water passing down through the Galena limestone has been deflected by the impervious oil rock, or more strictly by the shales which lie below the oil rock, and has worked its way laterally into the drainage limes of the district. This water would carry in solution, in the same manner as has been before explained, salts of lead, of zinc and of iron, and they would be precipitated by hydrogen sulphide and by a mingling of solutions in the same manner as has been explained in the formation of the deposits of ascending

waters. But in the case of the disseminated deposits the carbonaceous matter of the oil rock and the adjoining strata has also undoubtedly had a very important role to play. These deposits clearly seem to be the results of descending waters, but whether these waters obtained their ores from crevice deposits high up in the strata or from minute quantities of ores scattered in the Galena limestone is as yet uncertain. Quite probably ore was obtained from both these sources. As to the date of the formation of these disseminated deposits little can be said, although it seems probable, certainly so if the explanation here given is correct, that they have been largely deposited since the streams of the district cut down to and through the oil rock horizon.

Whether the oil rock and the accompanying shales have acted in deflecting and precipitating ore solutions which have come from below them, is not clearly shown in the deposits studied. That such may have been the case is probable.

LOCALIZATION OF THE ORE DEPOSITS.

Chamberlin in his report made many references to the fact that the ore deposits were located in synclines. The writer has been unable to add any information on this point. But it does seem to be a fact, attested by such observations as he could make, by the diagrams brought out in Chamberlin's reports, and by the statements of a number of intelligent mining men, that the oil rock along one pitch dips towards the other pitch. This means that each series of flats and pitches is within a small syncline. Whether these are really the synclines which are mentioned by Chamberlin is doubtful, and it seems to the writer that they are of such small extent that they can not be referred to the main synclines of the district, which can be and are represented on the geological maps. The oil rock and the shales and clays below it are, at least as far as seen, considerably thicker under the ore deposits than in other exposed locations. Attention has been called by Chamberlin to the fact that in the formation of these synclines conditions were probably favorable to fracturing and to the production of the peculiar crevices in which the flats and pitches of ore accumulated.[1]

[1] Geol. of Wis., vol. iv, pp. 482–488, 1882.

It seems to be clear that the ores have accumulated in the zones of maximum disturbance or maximum fracture, and where this fracturing has been of sufficient intensity to penetrate through the shales and clays which separate the Trenton from the Galena there is reasonable expectation that the ore deposits will extend down a considerable distance into the Trenton. Such a case exists a few miles west of Shullsburg in a district which was worked some years ago by the Wisconsin Lead and Zinc company. Here at one place (Little Giant mine[1]) a series of flats and fractures were found in the upper, more brittle parts of the Trenton limestone, and these were traced 12 feet below the oil rock, and intelligent mining men say that they have traced these same deposits with the same general richness 22 feet further in depth. At the time this examination was made, however, these lower levels could not be reached on account of water.

And this brings us to another important question, and that is whether mining can as a rule be carried on profitably at any considerable distance below the separation between the Trenton and the Galena. To this question the writer is able to give no definite and precise answer. From the facts of observation which have accumulated during the sixty or seventy years that this district has been mined, there are not many important ore deposits known below the oil rock horizon. At the same time it should be said that the Trenton has not been carefully explored in any one of these areas of maximum fracture or below any one of the main areas of flats and pitches in the district. Until such careful exploration has been made in a number of places, it will be impossible to answer definitely the question as to the extent of these deposits in depth. It can be stated, however, with a considerable degree of certainty that no deposits of importance are to be expected in the St. Peter sandstone, while for deposits in the underlying Lower Magnesian limestone the same statements can be made as have been made for the Trenton.

However, for our present purposes it is not important to

[1] *See p. 72.*

answer the question as to whether ore deposits continue deep below the oil rock horizon, for there seems to be most excellent reason for believing that within the lower part, say the lower 75 feet of the Galena limestone and the upper part, perhaps the upper 15 feet, of the Trenton limestone, there exists such a quantity of lead and zinc ore, especially zinc ore, that the supply will not be exhausted for a number of years to come. This statement is made after a careful consideration of the facts in the case and a study of the mines which have been recently opened up. It is only within the last few years that much mining has been done at levels below the water table. And what mining has been done seems to have demonstrated in a large number of cases that below the old ranges, which were worked in past years for large quantities of lead ore, are other deposits of zinc ore with minor quantities of lead. While it is not probable that each one of these lead bearing crevices traced down will develop into a series of flats and pitches carrying large quantities of lead and zinc, still there is every reason to believe that very many of these crevices do this. In this connection it might be well to quote the statement made by Chamberlin some twenty years ago, a statement which work in the district since that time, and especially that which has developed within the last two years, has shown to be eminently true.

Probabilities of ore below given horizons.—Where lodes have been mined in the upper measures of the Galena limestone, and work has been suspended by reason of water or other practical difficulties, there is strong presumption of valuable deposits below. These may be shifted along the crevice or to one side, according to the drift of subterranean drainage. The relations of the "twelve foot opening" deposits to the "sixty-five foot opening" at Muscalunge may be studied with profit on this point.

In the middle and lower portions of the Galena limestone where lead ore alone has been found at higher horizons, we deem it altogether probable that mixed lead and zinc ores occur. The progress of mining seems to indicate that zinc ores are more widely and abundantly distributed in the lower beds than has been heretofore supposed. It may be quite unsafe to assume that beneath all the lead deposits there is a corresponding formation of zinc, and that every

crevice that is lead-bearing in its upper reaches will develop zinc below, but such is the general tenor of evidence, and the general presumption is in favor of this as a rule. It would manifestly be of the greatest importance, it if were possible, to determine any definite ratio between the amount of lead in the upper beds and that of zinc below. In our previous discussions, pages 472, 488, we have alluded to this subject and have given some facts bearing upon it, facts which, we think, have not been generally known, or appreciated, in their bearing upon this important practical question. If the results of experience in a few of the most important mines of the whole region, from which the most of reliable statistics have been obtained, are to be taken as fair representatives of the general fact, which may be doubted, we shall be justified in concluding that an amount of zinc equivalent to that of lead might not be far from the general rule. But I must say, candidly, that I deem such a deduction too uncertain to be much trusted. But that greater richness in zinc in the lower beds is being, and is likely to be developed, than has heretofore been indicated by some of my official predecessors seems to me scarcely questionable. I incline to the judgment, therefore, that this region, in which the annual zinc product already far surpasses that of lead, and which should rather be called now the zinc district than the lead region, will continue to develop an increasing relative importance in the latter resource.[1]

As to the question of the discovery of large numbers of other ranges, especially in the areas which have yet produced no ore, no complete answer can be made. It is of course true that new ranges are being discovered from time to time, and old ranges are being extended. But the facts (1) that there are hundreds of these ranges already known, only the upper parts of which have been mined, and (2) that below at least many of these there are very good reasons to expect as rich or richer deposits of zinc and of lead ore, are sufficient reasons for believing that the future will see more zinc ore produced from this district than has been produced in the past; but it is doubtful if the same statement can be made in reference to lead.

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[1] Geol. of Wis., vol. iv, pp. 567–568, 1882.

CHAPTER VII.

GENERAL CONSIDERATIONS.

MINING.

Mining in this district has been carried on for the last seventy years and is today in many parts of the district done in the same primitive manner that it has been for years past. There still are many lead and dry-bone diggings which are worked only a few weeks or a few months in the year, when the owners are not engaged in the work of farming. In these small mines the work is of a very primitive character and will probably continue to be such. At the same time these mines have produced, are producing, and in all probability will continue to produce for a long time to come considerable quantities of zinc carbonate and galena.

The recent activity in mining in this district has developed a number of mines which are operated on a more extensive plan and which have been able by the introduction of machinery to mine at a considerable distance below the level of ground water. At the same time these mines are not as a rule run on very extensive principles. In none of them at the present date is steam or compressed air or electricity used for drilling, although several of them will probably introduce power drilling shortly. In a number of instances some of the mines which are producing steadily find small gasoline engines of about twenty horsepower sufficient to pump the water and hoist the ore. The comparatively small expense and the somewhat primitive method of mining which is in vogue are necessary

results of the careful and cautious manner in which work has been resumed in this district in the last two years. There is no question but that the methods of mining will be improved and larger plants and better machinery will be installed as the mining progresses. In fact, this has been done already in some cases.

CONCENTRATING.

In the early days, and still to a considerable extent in the smaller mines, concentration is done by hand sorting and hand jigging. During the past two years, and mostly within the last twelve months, twelve mines of the district have installed and now have in operation (or in course of construction) concentrating mills. These mines are: the Kennedy and New Deal near Hazel Green, the Strawberry Blonde at Strawbridge, the Helena and the Sally Waters near Shullsburg, the Coltman near Benton, the Trego near Meekers Grove, the Ellsworth near Mifflin, the Enterprise at Platteville, the Graham near Platteville, the St. Rose near Platteville, and the Trego near Potosi. These mills are equipped with a series of crushers and jigs which are able to turn out from 10 to 40 tons of cleaned ore per day.

In concentrating the ore by jigging, it is found possible to separate the galena very completely from the blende, but it is practically impossible to separate the blende from the marcasite. The consequence is that because of the presence of marcasite in all of the ores, except in some of the disseminated ores, the zinc ores from this district bring a lower price than those from certain other districts. The presence of barite is also detrimental, as it is difficult to separate this from some of the heavy metallic minerals; but this latter mineral is found mixed with the ores only in small amounts and in few localities. As a consequence of the high percentage of marcasite in some of these ores, a considerable quantity of such ore cannot be used for spelter but is shipped to Mineral Point where it is used in the manufacture of zinc white and sulphuric acid.

In some of the smaller mines hand sorting of the ore is re-

sorted to and by this means it is frequently possible to separate considerable quantities of very pure zinc blende. At the plants which have concentrating mills, however, it is not found economical to resort to this method of hand sorting.

As a solution of the question as to what can be done with the large amount of marcasite in the concentrated ore, there has been established at the Trego mine near Meekers Grove a roaster and a magnetic separator. The process here employed consists in roasting the concentrated ore, which is composed of sphalerite and marcasite, until the surface of the marcasite has been oxidized. The whole ore then passes under a series of magnets which pick up the marcasite from the blende. By this means a high grade ore is obtained. One objection to the process of course is its expense, and another is the fact that the tailings still contain a quantity of zinc, which at the present time is lost. At the same time it seems probable that others of the mines, especially those in which the marcasite percentage is high, will in the future find it expedient and economical to install roasters and magnetic separators. If this is not done it will be impossible for some of the mines to produce spelter ore. And in those mines, which can produce ore of sufficiently high grade for the manufacture of spelter, it may be questioned whether further concentration of the ore by the removal of the iron sulphide would not be an economic gain. The advantage of the mines which contain very small amounts of marcasite, i. e. those of the disseminated class of ore deposits, has already been mentioned.

OTHER MINERAL RESOURCES.

Marcasite of course is found in greater or less amount in all mines and in some places it occurs in considerable abundance. This material, at least when mixed with the sphalerite, is used in the manufacture of sulphuric acid, and there is a small demand for the pure marcasite also.

In former years some quantity of copper ore has been shipped from the district. None is being mined at present and the writer has no information to give on this point addi-

tional to that in the former reports of the Wisconsin Survey, except to state that recently near Darlington a small amount of exploration has discovered a vein of copper from one to two inches in thickness. This has been followed for only a short distance, but an assay of the average material of the vein shows a content of 18.54 per cent. of metallic copper.

The building stones of the district are important, at least for local uses, and the lower half of the Trenton limestone, called the buff limestone, has furnished and will continue to furnish large quantities of stone. Further information on the building stones of the State will be found by consulting a report on that subject.[1]

There are also clays in the district which are of economic importance, both those which occur near the surface at the present time and are of the nature of residual clays (as for instance those used in the brickyard at Platteville) and second, the series of clays and shales which occurs near the junction of the Galena and Trenton limestones. Recent tests of the latter are said to have shown that they are especially well adapted for terra cotta work and some of the better grades of pottery.[2]

Sand for mortar is obtained in large quantities from the St. Peter and Potsdam sandstones, while road material can be obtained by crushing most any of the limestones and also from the residuary deposits of flint. Some of the upper beds of the Trenton limestone are sufficiently pure to burn to good lime.

FUTURE GEOLOGICAL WORK.

The geological work which was done during the past summer in this district, accompanied by careful conversation and discussion of plans with a number of the leading mining men of the region, has convinced the writer that the State Geological and Natural History Survey can be of important serv-

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[1] E. R. Buckley: "On the building and ornamental stones of Wisconsin," Wis. Geol. and Nat. Hist. Survey, Bull. iv, 1898.

[2] On the clays of the State consult E. R. Buckley: "The clay and *clay industries of* Wisconsin," Ibid., Bull. vii, 1901.

ice in the development of the mining interests of this district. To that end a brief outline of the geological work which remains to be done in this region is here given.

In the first place the district should be gone over carefully and a topographic map should be made on a scale at least as large as one inch to the mile with twenty-foot contour intervals. On this map should be shown not only the natural features of the district, but the roads and buildings and all cultural features appropriate to a map of this scale. In addition to this there should be shown by appropriate colors the geology of the district, and to this geology it will be possible to add by a system of colored contour lines an approximate representation of the level of the base of the Galena limestone. This level, of course, is a very important one in the mining industry, and an exhibit of this level on the maps will aid greatly in any exploration which is undertaken for ore.

In addition to this map, which should be made of the whole region, i. e. at least of Grant, Lafayette and Iowa counties, there should be made also considerably larger scale maps of the important districts and also of districts in which it is probable that mining will develop in the future. Of course it is greatly to be hoped that these larger scale maps can be extended over the whole of the three counties,but at this time this seems to be too expensive and too arduous an undertaking. These larger scale maps should be made in the field on the scale of at least four inches to the mile, and published on at least half that scale. The topography should be shown by ten-foot contour intervals. In addition to colors representing the geology of the district there should be contour lines showing approximately the altitude above the sea level at any point in the base of the Galena limestone, and possibly also of the base of certain other formations, such for instance, as the St. Peter sandstone. In addition to these features, the actual elevation of the dividing planes between the different formations should be determined by leveling in a large number of places. The advantage of placing such maps into the hands of those who are prospecting for lead and zinc ore is obvious. The district

in which prospecting may be advantageously done is shown at a glance, and, moreover, in any case information is given showing approximately the actual distance which one will have to sink a shaft in order to penetrate to the base of the Galena limestone. It might be stated that the maps made by the early geological survey of Wisconsin, both the topographic and geologic, are extremely useful maps. They are in fact peculiarly valuable maps when it is considered that they were prepared twenty years ago and prepared without appropriations adequate enough to enable geologists to work over the whole district carefully. These maps are now out of print and it is advisable that they should be replaced by more accurate and larger scale maps.

Going hand in hand with this topographic and geologic mapping there should be made a careful and detailed study of the geology and ore deposits of the district. When this map and this geological study are completed,—and it is only by such detailed mapping and such detailed study that we can hope to arrive at anything like a complete understanding and a complete explanation of the origin and nature of these important ore deposits,—a monographic and authoritative account can be written of the whole district.

The writer conceives that in this manner the Geological and Natural History Survey can be and should be of great service to the people in this section of the country. These maps and the geological report would be of inestimable value to those engaged in mining, and of course it is unnecessary to speak of the value to any community of accurately and carefully made maps.

CONCLUSIONS.

In this report an attempt has been made to describe briefly the geology and ore deposits of southwestern Wisconsin, to describe them in such a manner as would be acceptable and understandable to those engaged in mining, and to offer such a description as would serve to give definite information to investors and mining men outside of the immediate district.

Some of the results of this work and of the mining that has been done thus far in this district may be summed up as follows:

First. The deposits near the surface of galena and smithsonite (dry-bone) are by no means exhausted. While these deposits probably will not play in the future as important a part in the mining industry of this region as they have in the past, there is reason to believe that they will continue to be important elements in the production of mineral wealth from this district.

Second. Where large deposits of smithsonite and galena have been worked in years past near the surface, there is exceeding good reason to believe that at least in many of these instances larger and still more extensive deposits of zinc ore exist farther down below the level of ground water, with at times important amounts of lead.

Third. In the lower 75 feet of the Galena limestone and the upper few feet of the Trenton limestone there probably exist in this district larger quantities of zinc ore than have yet been produced in the district. There is every reason to believe that the future will show the development of an extensive and important zinc and lead mining industry in southwestern Wisconsin.

Fourth. While the ore which exists near the base of the Galena limestone and the top of the Trenton limestone in the ranges already known is sufficient for a number of years to come, there is a probability that other ranges will be discovered, and there is a possibility that other deposits of economic worth may be found lower in the Trenton limestone and in still lower horizons, especially in the Lower Magnesian limestone.

Fifth. It may be stated that the most promising explorations (for sphalerite accompanied by some galena) for the immediate future should be confined to those ranges which have heretofore produced near the surface large amounts of galena, or galena and smithsonite. But ranges should be selected in which the level of ground water is some distance above the base of the Galena limestone.

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